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S. W. STRATTON, DIRECTOR

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THE EFFECT OF PRELIMINARY HEATING TREATMENT UPON THE DRYING OF CLAYS

BY

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BY

DRYING OF CLAYS
ING TREATMENT UPON THE
THE EFFECT OF PRELIMINARY HEAT-

NO. 1

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THE EFFECT OF PRELIMINARY HEAT TREATMENT UPON THE DRYING OF CLAYS

By A. V. Bleininger

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1. OBJECT OF THE WORK

This investigation has been undertaken for the purpose of looking into the possibility of using the excessively plastic clays, which on drying by any commercial method show great losses due to cracking and checking, by subjecting them in the crude state to a preliminary heat treatment before working them by the usual methods. There are, especially in a number of the Western States and on public lands, many clays of this sticky, heavy type which

resist all ordinary modes of preparation. To this class of materials belong the so-called joint and swamp clays of the glacial regions of Ohio, Indiana, Illinois, Wisconsin, Minnesota, North Dakota, and other States and Territories.

In order to bring out clearly the various effects of such a preliminary treatment, extensive laboratory experiments have been made on small and large samples of widely differing plastic clays. Preheating, rather than other possible treatments, such as the admixture of sand or sandy clay or the addition of salts like sodium carbonate and sodium silicate, has been chosen, since the mixture with nonplastic materials like sand presupposes the presence of the latter within a reasonable distance, which frequently is not the case; on the other hand, the incorporation of soluble salts even in very small amounts may give rise to the appearance of disagreeable efflorescence on the surface of the ware. Still other means of dealing with this problem, such as the exposure of the dug clay to freezing during the winter or drying out in the summer, are not always practicable nor effective. Furthermore, mechanical drying has become a well-developed feature of many industrial processes, and its cost is in part compensated by the resulting regularity of the manufacturing process, the possibility of eliminating objectionable mineral detritus like gravel, lime pebbles, etc., and other desirable features.

2. GENERAL CONDITIONS OF DRYING

(a) **The Plastic State.**—The use of clay in the arts depends upon its plasticity, the property of retaining any shape into which it is molded, supplemented by its quality of hardening to a stone-like mass when dried and burnt. The cause of plasticity has been made the subject of elaborate discussions,[1] but as yet no exact explanation has been found for it. The most convincing experimental researches[2] ascribe the phenomenon of plasticity to the presence of colloidal substances which behave in many respects

[1] For an excellent summary, see Heinrich Ries: Clays, Their Properties and Occurrence.

[2] Schloesing: Compt. Rend. **79**, pp. 376–80, 473–77, 1874. Van Bemmelen, Zs. f. anorg. Chemie, **18**, 14–36, *18*, 98–146. Cushman, A. S., The Colloid Theory of Plasticity, Trans. Am. Ceramic Soc., **6**, 65–78; On the cause of the cementing value of rock powders and the plasticity of clays, J. Am. Chem. Soc. **25**, 451–468. Ashley, H. E., Bull. 388, U. S. Geological Survey.

similarly to the typical colloids, such as silicic acid, ferric hydroxide, aluminum hydroxide, gelatine, glue, etc., in that they show the phenomena of hydrolysis, osmosis, adsorption, the ability to change from the gel to the sol form and vice versa in the presence of an excess of positive or negative ions, the property of shrinking in apparent volume down to a certain point proportionally to the loss of water, and the character of their dehydration and vapor tension curves.

This view therefore appears to offer the most satisfactory basis for explaining the properties of clays and seems to reconcile some of the older theories which have been proposed.

We may then assume that the cementing substance of clays is represented by some colloid, not necessarily of a definite chemical composition nor always of the same physical character, which possesses a more or less marked micellean structure in which water is held in the free and absorbed condition. Owing to the fact that clays are of different origins and are subjected to various modifying conditions during and after deposition, it is very probable that they are made up of colloidal substances, which vary widely as regards their physical structure. Thus the clay substance of the light burning, plastic clays is bound to differ considerably from that of the red burning surface clays and shales, not only in amount, but in character as well. Again, in many clays, especially those of primary origin, the transition of the crystalline matter to the colloidal condition still goes on, due to weathering and other agencies. This applies particularly to materials of the kaolin type. In other types the colloidal clay substance, has been in part "set" by certain geological conditions, though not irreversibly. In these a close and dense structure prevails which does not absorb water until the latter is forced into the pores by grinding and pugging. Clays of this type therefore show but a feeble initial plasticity, but become workable by energetic mechanical treatment. Fire clays and shales are especially apt to show this kind of behavior.

It seems to be a fact, however, that plasticity as measured by the ability of the clay to be molded, and to flow through dies, is dependent upon the development of this water-saturated micellean structure.

Equally important with the degree to which this condition of the cementing substance is developed is the amount and character of the nonplastic constituents of the clay which affect the plasticity as well as the resulting density of the clay body. This inert mineral matter, consisting of grains of quartz, feldspar, mica, limestone, pyrites, augite, hornblende, etc., not only dilutes the plastic clay substance, but by virtue of its granulometric composition, becomes a prominent factor in determining the resulting plasticity, drying shrinkage, ease of drying, and final density.

Since it is necessary to assume that each grain of nonplastic material be surrounded by an envelope of plastic substance, it is readily seen that the extent of the surface exposed by these particles is of great importance in regard to the plasticity and capillary structure.

Considering the subject theoretically and assuming that the crystalline grains are spherical in shape and fill a certain unit volume as compactly as possible, it can easily be shown that the total pore space remains constant at 30.3 per cent of the total volume, but that the surface exposed by the grains varies. If, for instance, the size of the particles were reduced from a diameter of 0.75 mm to 0.25 mm, the total surface exposed under the above conditions would be three times as great as before. On assuming a reduction in size from 0.75 mm to 0.125 mm, the surface would become six times as large. Or, speaking more generally, the surface exposed by different sizes of grain would be inversely proportional to the diameter. The surface of compactly arranged spherical particles in unit volume would vary as $4.1845\ (1 \div d)$, i. e., proportionally to the product of a constant and the reciprocal of the diameter.

Assuming that each particle must receive an envelope of plastic matter of uniform thickness, it is evident that the smaller grains would require a larger amount of this material than the particles of greater diameter. It is conceivable, therefore, that a definite volume of clay might prove insufficient to coat a large number of very fine grains, while the same quantity would be ample for an equivalent volume of larger, nonplastic particles. In the latter case, therefore, we should expect to find greater mobility of the mass as a whole, owing to the thicker enveloping layers which are

made possible, i. e., the larger grains reduce the plasticity of the clay less than the finer. By analogy it appears, then, that the tensile strength of the clay would be the greater the larger the average size of the granular matter, provided the total amount is kept within proper limits.

If the nonplastic particles are not uniform in size, it is evident that the pore space between the granular skeleton is decreased and it is possible to assume a combination which will result in maximum density. Of two sands mixed with the same weight of clay, the one producing the smaller volume of clay-sand mixture will show the greater density. The granulometric relations holding between the various sizes of granular matter in clay are similar to those applying to cements, as shown by the experiments of Feret,[3] although, however, there are certain differences inherent in the nature of clay.

It is seen, hence, that not only the amount and character of the colloidal clay matter, but also the amount and sizing of the nonplastic constituents govern the resulting plasticity. In addition, other factors are bound to be of more or less influence, such as the shape of the nonplastic particles, the presence of organic matter, various salts, bases, or acids.

(*b*) **The Evaporation of Water from Clay.**—In making up dry clay with water to form a plastic mass which may be shaped and molded, the resulting volume is somewhat greater than the sum of the volumes of clay and water. In this condition the clay particles, both plastic and granular, are surrounded on all sides by a film of water, while small pools or drops fill the cavities and pores between the grains. A tortuous system of capillaries is thus established which are wider in some places and narrower in others. When placed in an atmosphere saturated with moisture, equilibrium conditions are reached when no flow of water whatever takes place in these minute channels. As soon as the humidity is lowered, however, evaporation begins to take place on the surface, and every particle of water thus removed must be replaced through the capillary channels from the interior. The rapidity of this movement depends upon the structure of the clay—i. e., whether the capillaries are fine and intricate or coarse and short—

[3] Bull. de la Societe d'Encouragement, 2, p. 1604; 1897.

and upon the temperature and humidity of the outside air. Open structure, high temperature, and low humidity result in maximum capillary flow and vice versa. Since the spongelike colloidal matter with its immense surface and fine pores offers the greatest resistance to the passage of water, it is obvious that in highly plastic clays the movement of the water through the capillaries must be very slow, it having been estimated that the resistance to this flow is inversely proportional to the fourth power of the diameter of the channels. The capillary flow continues to grow weaker until the films become very thin and finally break altogether.[4] The water remaining within the colloidal interstices and within the pores in isolated films is expelled with increasing difficulty, and, owing to its low vapor pressure, requires a high temperature for its complete expulsion.

Considering now the drying of clay from the experimental standpoint, the relation between shrinkage and loss of water during this process might be examined in a specific instance. The curves of figure 1 represent the linear shrinkage of a clay sphere in terms of the diameter in the dry state and the loss in weight expressed in per cent of the dry weight plotted against the time of drying in hours.[5] The sphere was 7.11 cm in diameter in the wet state and was carried through the drying stage in an oven maintained at a constant temperature of 60° C. When a loss in weight was no longer observed, the temperature was raised to 120°, and finally to 200°. In each case the same temperature was maintained until the weight was constant. It is noted that down to a certain point the rate of shrinkage is proportional to the rate of the loss in weight, then the shrinkage becomes less than the loss of water, and finally it ceases, while the clay continues to evaporate water. The point at which shrinkage no longer takes place and where the clay grains are supposed to come in contact with each other is used to discriminate between two kinds of water. On drawing through this point a line parallel to the abscissa, the water lost above it represents the shrinkage and that below it the so-called pore water. Neither term is rigidly exact, since in some materials, especially

[4] Studies on the Movement of Soil Moisture, E. Buckingham, Bureau of Soils, Bull. No. 38, p. 41.

[5] E. F. Lines, Note on the Drying of Clays, Trans. Am. Ceram. Soc., **10**, p. 146.

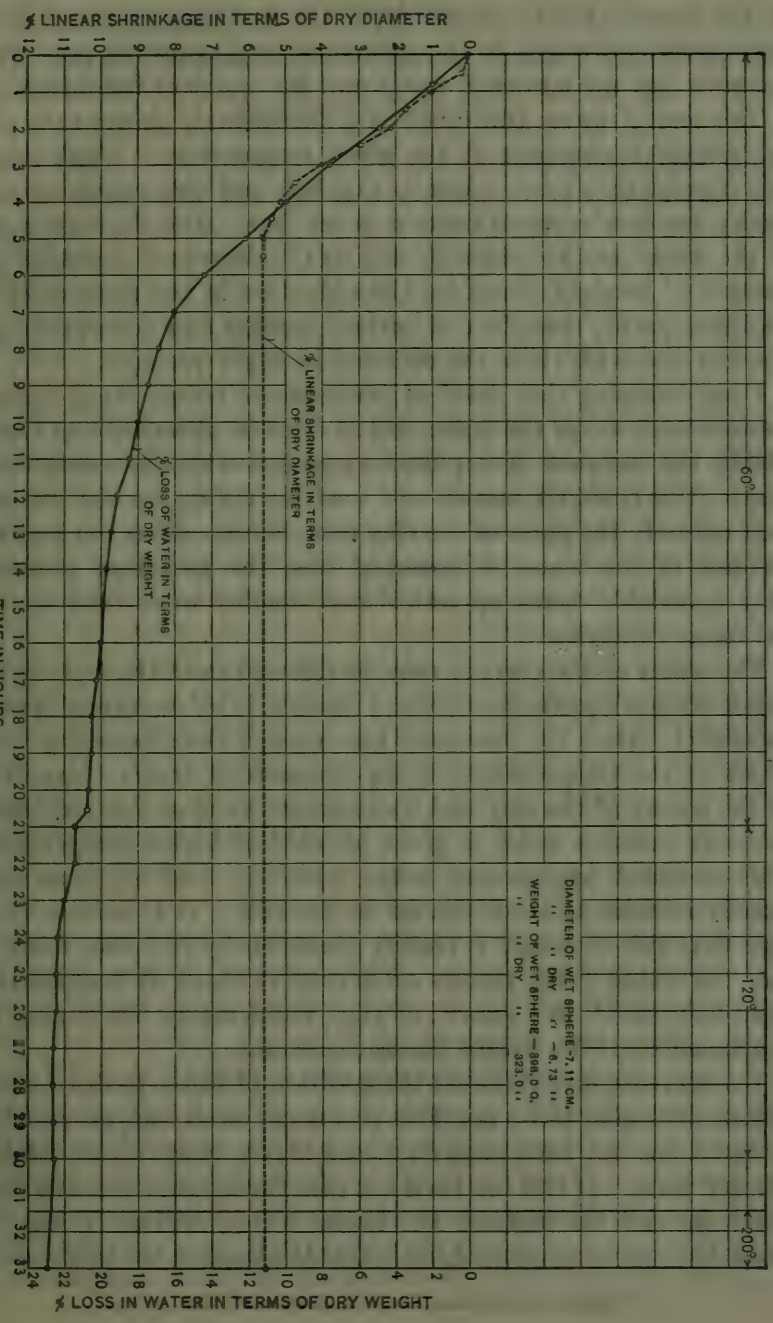
% LINEAR SHRINKAGE IN TERMS OF DRY DIAMETER
% LINEAR SHRINKAGE IN TERMS OF DRY DIAMETER
% LOSS OF WATER IN TERMS OF DRY WEIGHT
TIME IN HOURS
% LOSS IN WATER IN TERMS OF DRY WEIGHT
TEMPERATURE OF OVEN—°C.
60°
120°
200°
DIAMETER OF WET SPHERE =7.11 CM.
" " DRY " =6.73 "
WEIGHT OF WET SPHERE—896.0 G.
" " DRY " 323.0 "

Fig. 1.—*Relation between loss of weight and shrinkage in the drying of clay.*

of the porous, feebly plastic type, the first loss in water is not necessarily equivalent to the shrinkage, and again the pore water includes also the adsorbed water and the water of imbibition.

The loss of water continues at a decreasingly slower rate until the weight is constant at the given temperature. Upon raising the temperature more water is expelled and this continues until finally the last residual portion is set free. The decreasing rate of the water loss is evidently due to the decreased capillary conductivity [6] brought about by the reduction in the number of the capillary paths, the effect of surface tension and adsorption phenomena and with them the decrease in vapor pressure.

Upon bringing clay dried at atmospheric temperature again in contact with water the latter will at once be absorbed and the air within the network of capillaries expelled with the evolution of heat. The colloidal matter will swell in taking up the water so that not only the pores of the clay mass become filled, but a certain amount of the water is absorbed into the micellean structure. Clay invariably takes up water more readily in the dry than in the moist condition.

The water of the clay, as may be inferred from the fact that its vapor tension constantly becomes smaller, is by no means expelled completely when the specimen has reached the "bone-dry" condition at the temperatures of the commercial dryers. According to the nature of the clay and its structure more or less mechanical moisture remains which is given off only at higher temperatures. This so-called hygroscopic water which is held so tenaciously usually remains to be driven off in the kiln. It is evident therefore that this moisture is readily absorbed by dry clay from the air. In Table I the results of drying 12 clays at temperatures from 60°–200° C are shown; at each temperature the drying was continued until the weight became constant.

The increase in volume on the addition of water to dried clay is practically equal to its previous shrinkage on drying, provided the material has not been subjected to a higher temperature while in the dry state. If this has been the case the amount of water again taken up and the increase in volume will be distinctly less, and this is the more pronounced the higher the heating has been carried.

[6] Edgar Buckingham, Bull. 38, Bureau of Soils, p. 43.

TABLE I

Loss in Dry Weight on Heating

In per cent of the dry weight

	1	2	3	4	5	6	7	8	9	10	11	12
Loss at 200°.....	0.23	0.11	0.10	0.42	0.10	0.46	0.49	0.06	0.06	0.33	0.56	0.30
Loss at 150°.....	.17	.005	.16	.004	.10	.006	.34	0	.06	.001	.40	.12
Loss at 110°.....	.25	.11	.14	.40	.32	.32	.18	0	0	.11	.27	.005
Loss at 100°.....	1.56	.75	.93	1.17	1.30	1.28	1.36	.277	.24	.64	.85	1.20
Loss at 60°.....	59.84	20.17	37.92	38.84	45.61	42.40	29.19	28.72	45.87	24.59	30.72	49.80
Total loss.....	62.05	21.15	39.25	40.83	47.43	44.49	31.56	29.06	46.23	25.67	32.82	51.43

This is in accord with the results obtained by Van Bemmelen [7] with silicic acid gels in which he noted a distinct lag in the absorption of water on rehydration. He found that at first the liquid between the pores of this colloidal material left at a rate corresponding to the evaporation of free water. This was found to hold true for a water content of from 120–125 molecules.

Below this point the liquid within the micellean interstices evaporates at a continually slower rate owing to the narrowing of the capillaries. Also the vapor tension of the colloid decreases steadily, corresponding to the decrease in the content of absorbed liquid. At the same time constant changes occur in the physical condition of the substance which are slow at ordinary but accelerated at higher temperatures.

Van Bemmelen studied the inversion points by placing the silicic acid gels into desiccators containing 36 concentrations of sulphuric acid and hence corresponding to 36 aqueous tensions. He found several inversion points in the resulting dehydration curve. First, the substance becomes dull and fluorescent, then white like porcelain, and finally opaque white, like chalk, without gloss. This inversion changes the dehydration curve, since for a distance it runs parallel to the abscissa. The capacity to hold water then decreases more rapidly than before the inversion point. On continuing the dehydration still further the dimness disappears just as it appeared. The gel becomes porcelainlike, of bluish

[7] Zs. f. anorg. Chem. *18*, 14–36; *18*, 98–146; 20, 185–211.

fluorescence, and finally as clear as glass, remaining thus until the final dehydration. Also, when the gel is at once exposed to higher aqueous tensions, after the inversion, it becomes gradually homogeneous and clear as glass. These inversions may be repeated, and they are hence reversible under certain conditions. It is evident therefore that certain changes occur in the micellean structure of the colloid at these inversion points forming new coagulations which disturb the continuity of the dehydration curve.

By taking now the silicic acid pats which have been carried on to the lowest aqueous tension (most concentrated sulphuric acid), and placing them in the desiccators containing the more dilute sulphuric acid solutions rehydration takes place. Van Bemmelen in again plotting the molecules of water at each stage against the aqueous tension then found that the dehydration curve was not reproduced, but that a distinct lag was observed analogous to hysteresis—i. e., while a certain aqueous tension in the case of the fresh silicic acid corresponded to a certain amount of water, the same tension in the rehydrated substance was equivalent to a smaller amount of water.

While a homogeneous substance like silicic acid is not strictly comparable to a heterogeneous mixture like clay, certain observations bearing on the one might be utilized in connection with the other. The question which naturally arises is to what extent the plasticity of clays and its related phenomena, such as shrinkage, are reversible on heating clays up to temperatures still considerably below the dehydration point at which practically all clays lose their working quality completely. It has generally been understood that, up to the temperature at which the combined water is expelled, the plasticity and water absorption are to a large extent reversible; that is, the clays are able to resume a large share of their original plasticity. On the other hand it has been realized that a certain lag is observable since in pottery work it has been found that the dried ware which is again returned to the plastic state does not possess the same working quality on the jigger that it possessed originally. Whether on sufficient working and aging the clays would resume their initial plasticity is an open question, though it would seem very likely that this would be the case as far as the usual dried clay is concerned.

(c) **Shrinkage.**—In a general way the conditions governing the rate of drying of clays have been indicated. As has been pointed out the true volume of the dry clay plus the volume of water required to produce plasticity is less than the resulting apparent volume of the mass. This may be due to air mechanically inclosed, to flaws in molding, and volume changes due to the action of dissolved salts upon the clay gel.

In a series of experiments the volume changes taking place on working up a number of dry clays have been measured very carefully, the results of which are compiled in Table II.

TABLE II

Volume Changes in Working Dry Clays

Clay	Spec. Gr. of clay dried at 100°C	Weight of dry clay, grams	Weight of water added, grams	Volume of wet test piece, cc	Volume of clay plus volume of water, cc	Increase in volume in per cent of volume of test piece
Plastic high-grade clay, Tennessee	2.440	30	12.04	24.80	24.33	1.89
High-grade plastic clay, New Jersey	2.590	30	11.20	23.80	22.78	4.29
White plastic fire clay, Texas	2.587	30	11.78	24.30	23.38	3.53
Common glacial clay, Minnesota	2.464	30	11.51	23.80	23.68	0.50
Common glacial clay, Illinois	2.599	30	13.00	21.20	20.54	3.11
Alluvial clay, very plastic, Ohio	2.504	30	18.46	21.50	20.44	4.93
Common glacial clay, New York	2.703	30	18.41	19.70	19.51	0.96
High-grade plastic clay, Tennessee	2.585	30	13.96	26.90	25.57	4.94
Glacial clay, very plastic, North Dakota	2.655	30	15.80	28.00	27.10	3.21
High-grade kaolin, England	2.583	30	10.32	23.10	21.93	5.06

A short experimental series was also undertaken for the purpose of showing the rate at which several clays lose their residual water when subjected to conditions of decreasing vapor tensions. Five clays were made up into thoroughly homogeneous plastic pastes and placed into tared capsules provided with tight ground lids and weighed.

The clays thus treated in the order of their app
and difficulty of drying are as follows:

No. 1. An impure, exceedingly plastic glacial
Pierre, N. Dak.

No. 3. A ball clay from Whitlock, Tenn., throu
Supply Company.

No. 6. A very plastic kind of fire clay from Edwards County, Tex.

No. 7. A plastic glacial clay from Albert Lea, Minn.

No. 10. A high grade English china clay, Pool No. 1.

Of each clay five such samples were prepared. Five concentrations of sulphuric acid were then made up, of which a sufficient quantity was poured into each of five desiccators. These solutions of sulphuric acid represented final vapor tensions of from 12 to 0.15 mm, at 25° C, taking the water given off by the clays into account. After weighing the closed capsules containing the clay samples, which averaged about five grams, the covers were removed and one pat of each clay placed in every desiccator. They were allowed to remain in these for 21 days when they were again weighed. The room temperature fluctuated between 21° and 26° C. It was thus possible to compare the water losses suffered by each clay for the difference in vapor tension given above by subtracting from the percentage of water at 12 mm the percentage contents at the lower tensions. In this way the curves of Fig. 2 were obtained. In these only the residual water is considered, beginning with the amount of water left under a vapor tension of 12 mm to which all clays were subjected. It is at once observed that the amount of the residual water varies, being largest, 5.3 per cent, in the case of No. 1 and lowest, 0.85 per cent, for No. 10. The more plastic and "sticky" clays, therefore, show the highest water loss for the given difference in vapor tension. It is evident from this that the rate of drying at a constant temperature likewise varies for the different clays being slowest in the most plastic materials. These facts indicate not only varying amounts of plastic clay base in the different clays, but deep-seated variations in the micellean structure itself as well, since it is hardly probable that the larger content of residual water remaining in an impure material such as No. 1 could be attributed to a higher content of theoretical clay substance ($Al_2O_3 2SiO_2 . 2H_2O$) than is contained in the far purer clays Nos. 3, 6, and 10.

After having been replaced in the desiccators the samples were again weighed after three months and were found to possess practically the same weight. It seems thus that the conditions of equilibrium had been approached sufficiently close for the purpose of the experiment.

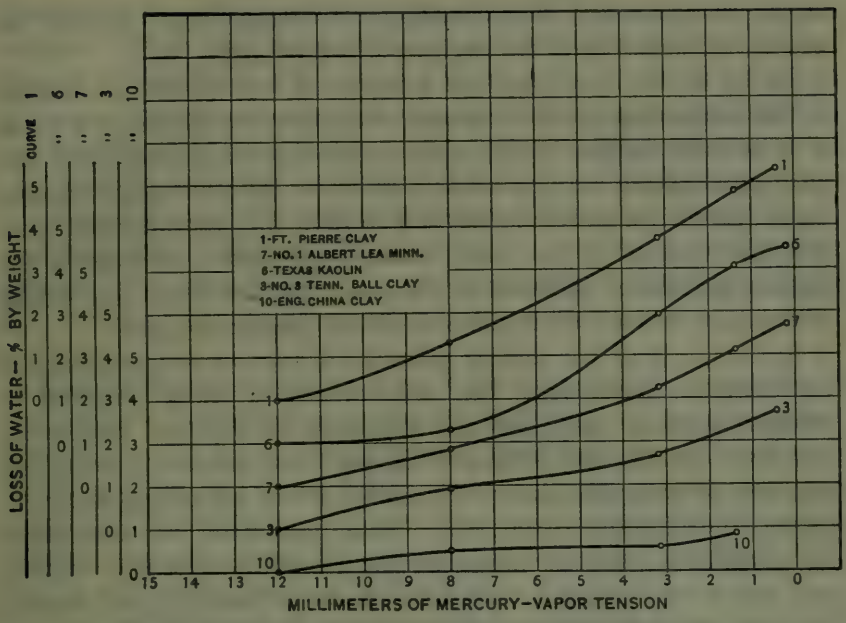
LOSS OF WATER—% BY WEIGHT
CURVE 1 6 7 3 10
1-FT. PIERRE CLAY
7-NO. 1 ALBERT LEA MINN.
6-TEXAS KAOLIN
3-NO. 8 TENN. BALL CLAY
10-ENG. CHINA CLAY
MILLIMETERS OF MERCURY—VAPOR TENSION

Fig. 2.—*Relation between loss of water and vapor tension of five clays.*

The drying shrinkage of a homogeneous clay body of geometrical symmetry, free to contract, is uniform in all directions. The most accurate valuation of shrinkage is obtained by means of volume measurements, though for practical work the linear dimensions in the wet and the dry state will suffice. The linear shrinkage is readily deduced from the volumetric values by the relation:

$$\% \, l = \frac{\sqrt[3]{v_1} - \sqrt[3]{v_2}}{\sqrt[3]{v_1}} \, 100$$

where v_1 and v_2 are the volumes in the wet and the dry state, respectively, and l is the linear shrinkage in terms of the wet length. If the linear contraction is desired in terms of the dry length, the denominator of course becomes $\sqrt[3]{v_2}$. The assumption commonly made that the volume shrinkage is equal to three times the linear shrinkage is not sufficiently exact even for practical purposes. If the initial (wet) volume is assumed to be unity and a = linear shrinkage, the dry volume becomes $(1-a)^3$,

or $1-3a+3a^2-a^3$. The shrinkage, therefore, $=3a-3a^2+a^3$, in which the term a^3 may be neglected, but not $3a^2$.

Owing to the fact that the amount of water used in making up the same clay is not constant, the apparent volume of a lump of a definite weight of dry clay varies somewhat even with the most painstaking manipulation. Likewise the pore space remaining in the dried material does not remain the same in each case. For this reason it has been thought advisable to express the volume shrinkage in terms of the true clay volume; i. e., weight of dry clay divided by its density in the powdered state.

In the study of the drying behavior of clays two factors are of considerable significance, viz, the amount of water required to produce a plastic mass and the shrinkage on drying. Ordinarily the more plastic and difficultly drying clays require the highest amounts of water and show the greatest drying shrinkage, although there are exceptions to the rule. Some materials, owing to peculiar conditions, such as excessive fineness of the granular matter, may dry more difficultly with lower water of plasticity and shrinkage than clays with higher water content and shrinkage.

In seeking for approximate values expressing the drying behavior of a clay by means of an experimental test it is necessary to know the total amount of water required to develop plasticity, the volume shrinkage, and the time required to evaporate the shrinkage water at a constant temperature. This means that the length of the test specimen must be carefully measured at short intervals. Then, knowing the time required to reach the point at which shrinkage ceases, and the total shrinkage, an estimate may be made of the drying behavior of the clay by multiplying together the values obtained for time and shrinkage. This numerical expression is inversely proportional to the ease with which it dries.

For the purpose of illustration the following description of a similar experiment might be cited.[8] Spheres of clay 7.11 cm in diameter were made, maintained for some time under conditions of moisture saturation in order to establish a condition of equilibrium, and then placed in an oven at a constant temperature of 60° C, regulated by means of a thermostat. The diameter of

[8] E. F. Lines, Trans. Am. Ceram. Soc. *11*, 146.

the sphere was measured from time to time by means of a vernier caliper. Thus the point was determined at which shrinkage ceased. A shale was found to possess a linear shrinkage of 4.0 per cent in terms of the diameter in the dry state, and it lost its shrinkage water in 4 hours. The factor in this case would be $4 \times 4 = 16$. Similarly, a washed No. 2 fire clay showed a shrinkage of 6.5 per cent and lost its shrinkage water in 5.1 hours, giving a value of $6.5 \times 5.1 = 33.15$. Finally, a fine-grained, glacial clay, very difficult to dry, possessed a shrinkage of 8.5 per cent and ceased contracting in 8.9 hours, resulting in $8.5 \times 8.9 = 75.65$.

Since these measurements were made under strictly comparable conditions as to drying temperature, initial size, and shape (spherical) of the test pieces, the numerical values are inversely proportional to the ease with which the clays dry in practice. The actual drying behavior of these clays was well expressed by the factors, the shale being the easiest and the glacial the most difficult to dry under commercial conditions.

Practically the same results could be obtained by determining the initial diameter and weight of the test piece, weighing it at frequent intervals, and measuring the size in the dried condition. The time when the calculated weight of shrinkage water (which should be equal in volume to the volume shrinkage) has been evaporated could be readily obtained from the time-weight curve.

The rate of drying has some influence upon the shrinkage of clays, inasmuch as rapid heating is said to result in a lower total contraction. As far as known to the writer, no experimental proof of this statement is at hand.

3. DIFFICULTLY DRYING CLAYS

Clays are subject to two kinds of difficulties in drying which are opposite in character. They may give trouble, due either to an excess of plastic material or to a deficiency of it. In the first case the system of capillaries is so extremely fine that the flow of water through it is very slow and becomes the more restricted as shrinkage progresses. Owing to the fact that such clays show a very large contraction in volume, the capillary channels necessarily become smaller and smaller on drying, thus causing the difficulty of expelling the water to increase.

(a) **Causes of Cracking.**—The result is inevitably that the rate of surface evaporation is greater than the flow of water toward the surface, a condition which gives rise to strains and more or less marked ruptures.

In the second case the amount of clay bonding matter is so low that the body does not possess the tensile strength needed to withstand the strain caused by the closing up of the particles near the evaporating surface. The result of this condition is that the clay gives way and cracks.

In order to overcome these two classes of difficulties, some remedial measures are available. These are for the excessively plastic clays dilution by means of nonplastic materials like sand or ground, calcined clay (grog), or drying of the ware under carefully regulated conditions with special reference to the maintenance of a high humidity in the drying until the clay has become uniformly heated throughout, or by using the preliminary heating treatment which is the subject of this work.

As regards weak clays, lacking in plastic clay matter, the means open for overcoming the difficulty consist in developing the available plasticity to its maximum by means of storing in the wet condition, by grinding and thorough pugging, by the use of slightly acid tempering water (in some cases), and finally by the incorporation of a more plastic material, which offers the most positive solution of the case.

(b) **Effect of Nonplastic Materials.**—The addition of granular, nonplastic material to an excessively plastic clay is made for the purpose of improving the working quality by reducing its "stickiness," decreasing the drying shrinkage, and with it the tendency to warp and crack in drying, and of lowering the kiln loss due to strains caused in drying and the impermeability of the dense clay to air needed for the oxidation of the organic matter present in all argillaceous materials. Nonplastic matter, intimately blended with the clay, thus exerts a decided influence upon the working qualities of the latter, affecting the penetration of water into the pore system, the shrinkage in drying and burning, as well as the porosity in the dried and burnt condition. Its effects, hence, are far reaching, since they are intimately connected with the final use of the product, its resistance to weathering agencies abrasion, etc.

When any granular, nonplastic material of uniform size is incorporated in a strongly plastic clay several effects may be observed. The volume shrinkage, providing the same percentage by volume of water is maintained, may be found to increase up to a certain content of the nonplastic constituent, but beyond this point it will decrease. The density of the clay mass may thus be said to increase to a maximum. After passing it the shrinkage decreases while the porosity rises. This effect is brought out more or less clearly according to the granulometric composition of the nonplastic material added and the initial content of such material in the clay.

It is evident that on introducing small amounts of a nonplastic material into a plastic clay the spongelike matrix envelops the hard grains and the total pore space per unit volume, assuming that the sand, or whatever material may be added is free from pores, has been decreased. If the total water content be kept constant, some of the pore water therefore becomes shrinkage water, with the result that the contraction in drying is increased. From this it follows that since the pore water, and hence the pore space, has been decreased in volume the density of the mass must have increased. Upon continuing the addition of nonplastic material the point is reached when contact is established between the incorporated grains, and therefore some of the shrinkage water again becomes pore water. Shrinkage therefore decreases from this point on and the porosity increases.

If in the case of a difficultly drying, exceedingly plastic clay it is decided to add sand for the purpose of making it easier to dry, this addition should be carried beyond the point of maximum density, so that a larger pore space, and hence an increased evaporation and outlet area is produced.

In tracing the effect of nonplastic matter the assumption has been made above that the water content be kept constant. If this condition is not fulfilled but the attempt is made to maintain constant consistency, the above facts still hold, although the effects are not so marked. In determining the drying shrinkage of five low grade, plastic clays with varying percentages of a very uniform sand (20–30 mesh), and at the same time aiming to keep the consistency constant, it was possible in each case to fix clearly the point of maximum density.

The size of grain of the nonplastic material is necessarily an important factor in the resulting density and the system of pore spaces. Fine-grained sand, for instance, at the point of maximum density will result in a more porous structure than coarser grained at the same point. With equal water content a fine nonplastic will bring about a stiffer consistency than coarser-grained material. As regards a mixture of grains of various sizes, the same statements hold that have been made with reference to the natural granular constituents of clays.

4. PREHEATING

(a) **The Clays Used in the Experiments.**—Since this bulletin deals solely with the study of the preheating treatment of clays and its effect upon clays, a detailed consideration of other methods bringing about similar results can not be undertaken at this time.

For the purpose of the investigation 14 clays were selected, covering a wide range of chemical and mineralogical compositions. Their character is indicated by the following descriptive remarks:

No. 1.—An exceedingly plastic clay, very similar in behavior to bentonite, from Fort Pierre, N. Dak. It is impossible to dry this material without cracking. Its fineness of grain is remarkable. Apparently it contains some calcium carbonate in a state of extremely fine subdivision.

No. 2.—St. Louis fire clay, Highland Fire Clay Co., St. Louis, Mo. A high-grade fire clay, but lacking in plasticity, owing to insufficient reduction of clay grains. Grinding at once improves the plastic quality simply by disintegrating the coarser, wax-like clay particles.

No. 3.—Tennessee ball clay No. 3 (Potter's Supply Co.), from Whitlock, Tenn. A clay of great plasticity and bonding power. It dries without difficulty excepting when fabricated into large pieces, when care must be taken to prevent cracking by maintaining a high humidity during the initial stages and by keeping the drying temperature down as low as possiple.

No. 4.—Prall sagger clay, Woodbridge, N. J., a decidedly plastic material of excellent bonding power and of safe drying behavior. It contains coarser grains of quartz.

No. 5.—Pike's No. 20 ball clay, a high-grade English plastic material which when used alone has a decided tendency to warp and which when made up into large pieces must be dried with great care to prevent cracking. Its bonding power, which makes it valuable, is very high and by some it is considered the strongest material of this kind on the market.

No. 6.—Texas kaolin, "Lone Star" brand, from Edwards County, Tex. A fire clay consisting of clay grains and extremely fine clay matter. Grinding increases the plasticity of this clay immensely and in this way it is capable of great improvement by the reduction of the comparatively coarse clay grains. It does not seem to give trouble in drying.

No. 7.—An extremely fine-grained glacial clay from Albert Lea, Minn., of considerable plasticity, but troublesome to dry.

No. 8.—Joint clay, from Urbana, Ill. A plastic glacial clay, difficult to dry, due not so much to great fineness of grain as to "joint" structure which is indicated by the fact that bricks made from it on drying split vertically into more or less irregular cubes.

No. 9.—Albany slip clay, a fine-grained glacial clay from northern New York, low in bonding power, but showing sufficient plasticity.

No. 10.—English China clay, J. Poole No. 1, considered a high grade of kaolin, not commonly imported, of excellent plasticity and yet producing a fine white color.

No. 11.—Joint clay, Peoria, Ill., a typical fine-grained glacial clay, giving some trouble in drying.

No. 12.—A typical alluvial clay from Groveport, Ohio, of decided plasticity, somewhat troublesome to work and dry. Probably quite high in ferric oxide, since on burning a fine red color is developed.

No. 13.—A No. 2 fire clay, highly impregnated with ferric oxide, from Athens, Ohio, very plastic, with some tendency to crack in drying though excellently suited for admixture with shale owing to its ease of slaking down on contact with water.

No. 14.—A glacial, calcareous clay from Heron Lake, Minn., possessing good plasticity and working properties though somewhat too fine grained for drying when made into larger pieces.

In the effort to correlate the drying shrinkage with the fineness of grain and the general plastic behavior of these different clays the following determinations were made:

1. Drying shrinkage in the normal condition.
2. Fineness of grain by means of the mechanical analysis.
3. Resistance offered by mixtures of clay and water to the passage of a paddle in the Stormer viscosimeter.

(b) **Drying Shrinkage.**—In determining the drying shrinkage of the clays they were made up with water to "plastic" consistency, which, in spite of its apparent indefiniteness, is a condition fairly sharply defined in the hands of an experienced operator. Owing to the fact that there exist no other means of maintaining a constant consistency, it was necessary to depend solely upon the judgment of the manipulator. In some preliminary experiments, however, it was shown that the water content representing good working quality could be checked for the same clay with satisfactory accuracy since at approximately the proper working consistency the clays are quite sensitive to a deficiency or excess of water. This property varies somewhat with different materials, very plastic clays being less sensitive to variations in water content than those higher in nonplastic matter. After having been allowed to stand over water for 24 hours the clays were molded by hand into approximately cylindrical test pieces which were at once weighed and their volume determined. The weighing was done in closed tin cylinders to prevent loss by evaporation. The volume of each cylinder was determined by immersion in petroleum making use of a narrow-necked flask and obtaining the volume of liquid displaced by means of a burette calibrated to 0.1 cc which permitted of easily reading to 0.05 cc. The weight of the clay cylinders varied between 20 and 35 grams and the volumes from 12 to 22 cc. After the determination of weight and volume the test pieces were dried at 60° till the weight was constant and finally at 100°. The dry specimens were then weighed and immersed in melted paraffine at a sufficiently high temperature so that the liquid penetrated into the interior, but dripped off completely on removing the piece from the bath. When cool the cylinders were placed in petroleum for several hours and the volume determined as before.

In Table III the volume shrinkage of the clays in terms of the dry volume of the cylinder and of the true volume of the clay as well as the linear shrinkage in terms of the wet length are compiled. For purposes of comparison the shrinkage referred to the true clay volume is to be preferred owing to the variable factor of the pore space which depends upon the character of the clay, the method of manipulation, etc.

The shrinkage expressed in terms of the real clay volume is readily calculated from the relation:

$$s = \frac{d\ (v_1 - v_2)}{w} \text{ where—}$$

s = volume shrinkage in terms of the true clay volume.
d = specific gravity of powdered dry clay.
v_1 = volume of clay cylinder in the wet state.
v_2 = volume of clay cylinder in the dried state.
w = weight of the dried cylinder in grams.

TABLE III

Shrinkage of Various Clays

No. of clay	Specific gravity of powdered dry clay	Volume shrinkage in per cent of volume of dry test piece	Volume shrinkage in per cent of true clay volume	Linear shrinkage in per cent of the wet length
1	2.451	68.57	99.80	15.97
2	2.551	23.40	30.30	6.77
3	2.770	38.10	60.73	10.20
4	2.596	34.50	54.80	9.41
5	2.577	48.19	61.96	12.28
6	2.510	36.80	60.10	9.92
7	2.580	36.20	49.00	9.79
8	2.603	30.30	41.85	8.44
9	2.784	16.90	25.80	5.07
10	2.476	21.05	34.80	6.17
11	2.575	32.20	49.00	8.89
12	2.680	37.86	51.09	10.15
13	2.768	38.00	49.05	10.18
14	2.645	27.30	42.65	7.72

The specific gravity of the clays was determined by means of the pycnometer with the usual precautions as regards exhaustion of the air and correcting for temperature.

The linear shrinkage was calculated from the condensation in volume.

The clays examined, with the exception of three, the Highland fire clay, the Albany slip clay, and the English china clay, belong to the more difficultly drying materials when made up into heavier products. The clay from Fort Pierre, N. Dak., is in a class of its own, and it appears to be impossible to dry it under any conditions.

(c) **Mechanical Analysis.**—The mechanical analysis as practiced by agricultural and ceramic investigators consists in the separation of grains of certain arbitrary size limits by means of sieves and further separation by means of sedimentation, elutriation or centrifugal action, water being used as the medium of flotation. For the purpose of the ceramist the Schulze apparatus, in which the separation of the grain is effected by the method of elutriation, is commonly used and meets the technical requirements owing to the simplicity and convenience of its arrangement. It consists of three tin-lined copper cans with conical bottoms, 2, 5, and $6\frac{15}{16}$ inches in diameter, respectively, through which water is allowed to flow at a constant rate, 176 cc per minute. It is readily seen that this results in the greatest velocity in the narrowest and the lowest in the widest can. With the diameters of the cans and the volume of water given, the largest particles settle in can No. 1, averaging about 0.0577 mm diameter, the next smaller in No. 2, averaging about 0.0354 mm, while in No. 3, the average size approximates 0.0167 mm. Particles still finer, about $\pm$0.005 mm, are carried off by the overflow.

The average size represents the microscopic measurement of 50 particles of each sediment and is the arithmetical mean. In this connection the difficulty of obtaining the true mean diameter is fully realized, but for the work in question this method has been preferred to the method of mean integrals, since it was not desired to calculate a surface factor. After the water escaping from the third can appears to be clear the cans are emptied by siphoning down to the conical bottom. The water and clay in this part of the cans is washed out, evaporated to dryness, and weighed. The amount

of the finest particles is obtained by difference. Before being placed in the elutriating apparatus the sample of the dry clay, the amount of which is usually 50 grams, is made up with water to form a thin slip, deflocculated by the addition of caustic soda or sodium oxalate according to the nature of the clay and mechanically shaken for one hour. The clay suspension is then passed through a series of small conical sieves, telescoped together, ranging from 20 to 120 mesh. After washing and drying the residues on each sieve are weighed. The material which passes the 120-mesh sieve is collected and introduced into the elutriating apparatus.

The water flowing through the cans is taken from the tap, but is filtered through beds of sand and charcoal. Its temperature is kept constant by heating to a certain temperature and regulation by means of a thermostat. The separation of the sediments is considered successful when the residues dry down without cracking. If the latter occurs, some of the clay matter has been retained, and the test is repeated, the clay sample being deflocculated more thoroughly or another reagent is employed such as sodium oxalate. In extreme cases the deflocculating solution is dropped slowly into the first can for a number of hours. Certain precautions must be observed in the operation of the elutriating apparatus, such as to start with a reduced flow of water until the first can appears to be comparatively clear when the current is brought to the standard velocity. The time required for the elutriation varies from 10 to 24 hours, according to the nature of the clay. When adjusted the device needs practically no attention.

The results of the mechanical analyses of the clays examined are compiled in Table IV.

From the results of the mechanical analysis a numerical value expressing the fineness of grain of the clay as a whole might be calculated. Since the weights of the fractions are known, the average diameters (by microscopic determination) and the specific gravity of the powder may easily be obtained a factor expressing the relative total surface area may be computed, which J. W. Mellor[9]

[9] J. W. Mellor, Jackson's and Purdy's Surface Factors. Trans. English Ceram. Soc. 9, p. 94–114.

TABLE IV

No. of clay	Residue left on sieves in per cent by weight of dry clay							Sediments left in can, in per cent by weight of dry clay			Per cent by weight carried off by overflow	Kind and amount of reagent employed per 50 grams of clay
	20 mesh	40 mesh	60 mesh	80 mesh	100 mesh	120 mesh	Total residues on sieves	Can No. 1	Can No. 2	Can No. 3		
1	.....	.....	.....	.....	.....	.....	2.32	0.35	0.39	1.12	95.52	1 c c $\frac{N}{10}$ NaOH
2	Trace	11.75	7.03	4.10	5.30	0.77	28.98	14.74	11.79	3.95	40.57	200 c c $\frac{N}{10}$ $Na_2C_2O_4$
3	.....	.....	.....	.....	.....	.....	Trace	0.02	0.24	0.43	99.31	80 c c $\frac{N}{10}$ NaOH
4	.....	.....	.....	.....	.....	.....	1.17	2.83	8.28	2.01	85.71	500 c c $\frac{N}{10}$ NaOH
5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	99.00	
6	0.05	0.18	2.93	2.60	5.35	0.85	11.96	13.65	19.07	5.14	50.18	50 c c $\frac{N}{10}$ NaOH
7	0.04	0.06	0.04	0.04	0.04	0.02	0.24	0.21	1.04	0.96	97.31	75 c c $\frac{N}{10}$ NaOH
8	0.61	1.49	1.74	0.63	0.55	0.11	5.13	3.15	34.50	9.72	47.50	100 c c $\frac{N}{10}$ NaOH
9	0.02	0.02		0.04			0.08	0.24	6.34	8.74	84.60	30 c c $\frac{N}{10}$ NaOH
10	.....	.....	.....	.....	.....	0.02	0.02	0.02	10.90	9.52	79.54	30 c c $\frac{N}{10}$ NaOH
11	0.33	0.66	0.35	0.16	0.27	0.04	1.81	2.28	34.09	10.69	51.13	100 c c $\frac{N}{10}$ NaOH
12	0.64	0.98	1.24	1.10	3.54	0.24	7.74	14.30	23.08	7.06	47.82	180 c c $\frac{N}{10}$ $Na_2C_2O_4$
13	1.54	1.83	2.86	0.96	2.22	0.18	9.59	5.66	8.54	8.24	67.97	
14	0.14	0.28	0.46	0.34	0.46	0.04	1.72	0.98	8.03	9.03	80.24	75 c c $\frac{N}{10}$ NaOH

expresses by the formula:

$$\frac{6}{s}\left(\frac{W_1}{d_1}+\frac{W_2}{d_2}+\frac{W_3}{d_3}+\ \ldots\right).$$

Here s = mean specific gravity of the powder, W_1, W_2, W_3 . . . the weights of the fractions, and d_1, d_2, d_3 the average diameters of the grains in the several fractions.

The greater the surface factor the finer is the material, and hence this value may be used to give a relative approximation which serves sufficiently well for purposes of comparison.

Where the limiting diameters of the fractions are known—i. e., the sizes of the largest and the smallest particles for every separation—the mean integral diameter may be calculated from the formula [10]

$$\sqrt[3]{\frac{(d_1+d_2)\ (d^2{}_1+d^2{}_2)}{4}}$$

[10] Mellor, loc. cit.

in which the limiting diameters are represented by d_1 and d_2. The value of this average diameter may then be substituted in the formula for the surface factor given above.

In all of this work the assumption has been made, necessarily, that all the particles are spherical in shape, which of course is not true. Again, the surface factor thus calculated can make no claim to scientific accuracy, owing to the fact that it is difficult to obtain the average sizes of the grains represented by the various sediments, and practically impossible to determine the mean dimension of the particles carried off by the overflow with any degree of correctness. Owing to the fineness of the material floated off its surface valuation constitutes the greater part of the total surface factor. Furthermore, many of the apparent grains are aggregates of still finer material, and it is almost absurd to speak of an average size for the clayey matter. The material carried off contains practically all of the plastic clay substance and in addition the finest particles of granular matter.

In comparing the clays as to their drying behavior the amount of overflow material expressed in per cent is used as the basis of comparison. Generally speaking, therefore, the statement might be made that clays should dry the more difficultly the finer grained they are, the more matter is washed out of them at the low velocity maintained in the third can of the Schulze elutriating apparatus, assuming that the clay substance is of the same character in all of them. Since the latter assumption, however, is inadmissible, the above generalization holds only in a limited sense, in comparing clays of one kind. Still further modifications are made necessary by the size factor of the granular matter, as has already been pointed out elsewhere.

Similarly, a statement to the effect that clays showing the greatest shrinkage are most difficult to dry can not be accepted without qualification for the same reasons applying to the question of fineness. Granted that the greatest volume shrinkage results in the greatest strain upon the clay structure, the fact remains that clays differ widely in tensile strength and hence in the ability to meet these stresses.

If in spite of these objections an attempt is made to differentiate between the clays as to their relative difficulty of drying, it

is evident that such a classification may serve only as a general guide. This approximation was obtained by multiplying the drying shrinkage expressed in terms of the true clay volume by the fraction carried off in the overflow of the Schulze apparatus. From this definition it appears that the higher the numerical value thus obtained the more difficultly should the clay dry other things being equal. The drying factors thus calculated are collected in Table V.

TABLE V

Drying Factors

Clay No.	1	2	3	4	5	6	7
A. Fraction carried off by overflow	0.955	0.406	0.993	0.857	0.990	0.502	0.973
B. Drying shrinkage in per cent of true clay volume	99.80	30.30	60.73	54.80	61.96	60.10	49.00
Factor A×B	95.31	12.30	60.30	46.96	61.38	30.17	47.67

Clay No.	8	9	10	11	12	13	14
A. Fraction carried off by overflow	0.475	0.846	0.795	0.511	0.478	0.680	0.802
B. Drying shrinkage in per cent of true clay volume	41.85	25.80	34.80	49.00	51.09	49.05	42.65
Factor A×B	19.90	20.83	27.67	25.04	24.43	33.35	34.17

(d) **Viscous Condition of Clay Suspensions in Water.**—In previous work [11] the writer has made the attempt to correlate the plastic behavior of different fine-grained clays by determining the tenacity of clay slips, representing various mixtures of clay and water, using a modified Coulomb viscosimeter. He was successful in differentiating several well-known clays in a way which agreed with practical observation. In carrying on these experiments it was fully realized, however, that the comparative results obtained do not express viscosity in its proper physical meaning, but that they represent complex functions, the resultant of which seems to be related to the plastic condition of the material. From practical experience it is known that the more plastic

[11] Trans. Am. Ceram. Soc. 10, p. 389.

a clay is the more power is required to force it through an auger machine or pug mill. Owing to the fact that we are dealing in this case with suspensions, it is evident that various factors enter into the question such as the viscosity of the water which has dissolved some of the salts contained in the clay, the mechanical resistance of the suspended granular matter, as well as that offered by the flocculent matter to the passage through water, etc. In addition the practical difficulty due to the tendency of the materials to settle must be considered. Owing to the fact that the latter feature is especially annoying, it was decided to make use of an apparatus employing a paddle in place of the disc. Such an instrument was found already on the market in the Stormer viscosimeter, which consists in brief of a vertical shaft to which a paddle is attached and which is driven by means of a simple gearing from a grooved pulley. Motion is imparted to the latter by means of a weight attached to the pulley by a cord. The weight used in these experiments was 200 grams. A revolution counter is connected to the vertical shaft. The method of operating the instrument is very simple. The liquid is poured into a square receptacle, taking care that the same level is maintained for each test. The cup is then raised so that the paddle is immersed and by releasing a brake the weight is caused to descend, thus revolving the pulley and transmitting motion to the paddle shaft. By means of a stop watch indicating one-fifth seconds the time required by the paddle to make 100 revolutions is determined. It is also necessary to obtain the time taken for the same number of revolutions in air, and to deduct this reading from every determination. The resistance offered by water is taken as unity by dividing the time required to make 100 revolutions with the paddle immersed in water into the time required to make the same number of turns in the clay suspension, deducting the air constant from each reading.

A brief consideration of the principle of the apparatus will show that owing to the variable speed in the different media the results are not strictly comparable. This together with the variable friction constant of the mechanism itself causes the variations in the experimental results to be quite large. How-

ever, for the purpose in view the object of carrying on this work was merely to obtain a rough classification of the clays as to their plastic character under the assumption that the resistance offered by clay suspensions of equal content in solids is a function of their plastic behavior, an assumption, however, for which a general proof has not yet been established. In this connection it was desired to locate by comparison certain of the clays examined which have been found to be especially troublesome in drying.

The preparation of the clays for the test consisted in weighing out a certain quantity of the dried material and of a sufficient amount of water and shaking them by mechanical means, so that the slip became as thick as possible and yet permitted the paddle to revolve. This heavy suspension was diluted gradually, so that the desired concentrations of clay were obtained. In this manner a number of dilutions were made and their relative resistances determined.

The initial clay suspensions were shaken in wide-mouth bottles containing a little shot to facilitate the breaking up of the clay particles. The slip was then shaken through a 20-mesh sieve and poured into the viscosimeter cup.

The results of this work are shown in the diagram of figure 3. In spite of the irregularity of the curves it is at once observed that the clays arrange themselves into three groups. That showing the most rapid increase in resistance or tenacity comprises the plastic clays of the purer type, including, however, one member of the impure clays, the material from Fort Pierre. The latter is of such a highly plastic nature that its presence in this group is not surprising. The second group contains all of the glacial clays which show remarkable similarity in this respect. In the third group the Highland fire clay appears, which, as the sole representative of its class, takes its proper place.

The higher degree of plasticity on the part of the purer clays is made very prominent, and this is due not only to the greater fineness of grain, since two of the glacial clays approach them in this respect, but primarily to the lack of granular matter which, though very fine, is ever present in the impure surface clays.

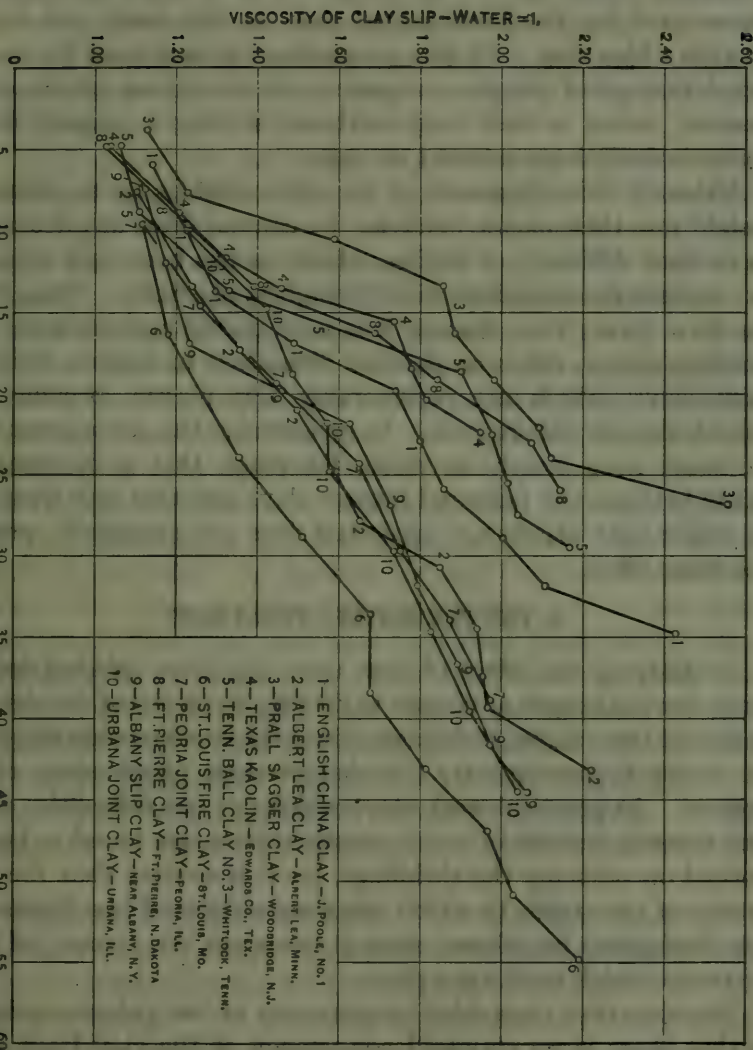

Fig. 3.—*Apparent viscosity of different clay slips with varying contents of clay.*

The latter may reach the highly plastic development of the purer clays, as is shown by the Fort Pierre material, but this is a rare exception. The extreme at the plastic side of the first group is represented by the Prall sagger clay, at the lower end by the English China clay. In this connection the fact must be remembered that all of the clays represent the maximum plastic development, owing to their long-continued stirring in contact with a comparatively large amount of water.

Although this alignment of the clays enables us to obtain an insight into their plastic behavior, we can not draw any deductions as to their difficulty of drying, which, as has been said before, is not necessarily coincident with the highest plasticity. Thus, No. 4, the New Jersey clay, though it is very plastic and possesses high bonding power, offers no decided difficulties in drying, while the joint clays, which are considerably less plastic, become very troublesome in this respect. In considering the subsequent work we must keep clearly in mind, therefore, that a dividing line exists between the pure and impure clays and that any treatment to which both classes are subjected does not necessarily produce the same effect.

5. THE PREHEATING TREATMENT

In studying the effect of heat upon the clays selected for this work it was thought advisable to do this by means of the determination of the volume shrinkages, since the condensation in volume on drying is preeminently the characteristic phenomenon of this process. In practical work clays which dry too difficultly, due to an excessive amount of highly plastic matter, are found to become normal on reducing the shrinkage, for it is evident that the magnitude of the strain to which clays are subjected is a function of the diminution in volume, since it measures the amount of readjustment which must take place.

The objection to making comparisons of the volume shrinkage is that there is no standard consistency of the clay from which to start, so that the amount of water to be used in making up the clays depends upon the judgment of the operator. Various methods for determining the consistency of plastic clay bodies have been proposed, such as the use of the Vicat needle, but none

of them give an accuracy greater than that obtained by the "feel" of the clay in manipulating. As has been pointed out before, the proper consistency is fairly sharply defined and any excess or deficiency in water is at once noticed by the expert operator. In the nature of the case, however, slight variations in the water content are unavoidable, especially in working with a material as heterogeneous as clay, of which perfectly uniform samples are difficult to prepare.

In carrying out the preheating experiments a sample of clay sufficient in amount for making all of the test pieces of the series was thoroughly worked and tempered and kept at least 48 hours in a large desiccator containing water, so as to establish conditions of equilibrium. Cylindrical test pieces for the determination of the normal volume shrinkage were then made up and their volume measured as described above. These specimens were then dried to constant weight at 60° C, and finally at 100°. Pats of clay of sufficient size were then removed from the bulk sample in the moist dessicator and dried to the following temperatures in a copper laboratory oven: 150, 200, 250, 300, 350, and 400° C, which were maintained for three hours. The dry pat resulting for each temperature was ground through a 20-mesh sieve and made up with water to its best plastic consistency. In one series of experiments these wet pats were kept over water for 16 hours, in another series for one hour. After this period the moist clay was made up into cylindrical test pieces, the volume of which was found at once. The specimens were then dried and their volume again determined. In addition to the volume both the wet and the dry weights of the test pieces were obtained. During the weighing the specimens were kept in tightly closed tin cylinders.

(a) **Effect upon Drying Shrinkage.**—The specific gravities of the normal as well as of the preheated clays in the powdered condition were carefully determined by means of the pycnometer.

The preheating oven consisted of a cylindrical, air-jacketed vessel of heavy copper, 6 inches in diameter and 5 inches deep inside, the air space being 1 inch. The cover likewise was provided with an air space and had three tubulatures for the insertion

of mercury thermometers. The heat was applied by a gas burner and the temperature regulated so that it did not vary on the average more than 5° from the desired point.

In working up the ground, preheated clays into the plastic state it was at once observed that the amount of water required decreased with the increasing temperature treatment, although

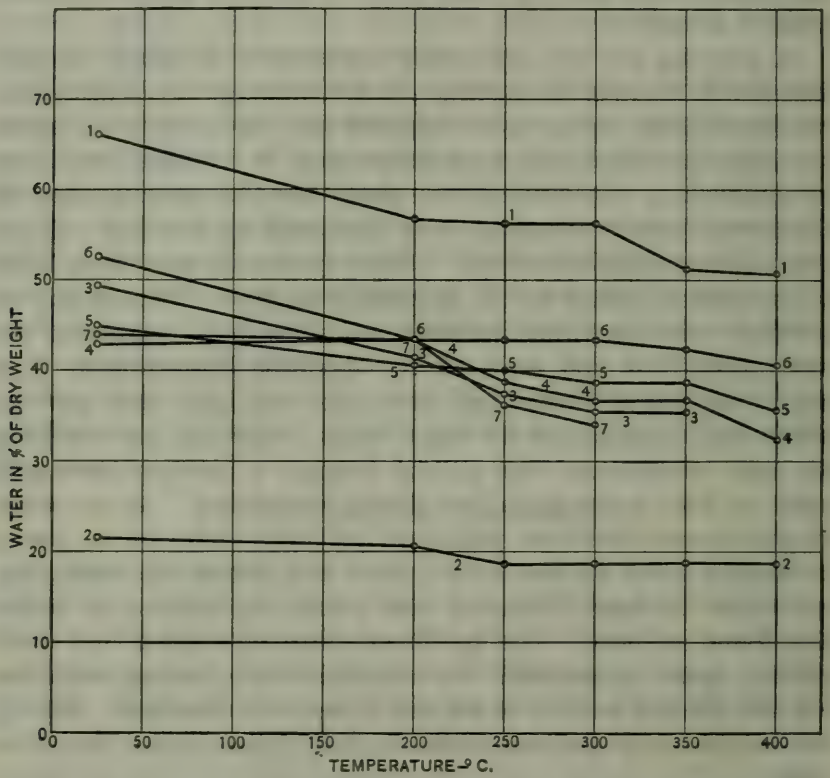

Fig. 4.—*Variation in water content for clays preheated to different temperatures.*

not in a regular manner, as shown by the curves of Fig. 4, representing seven clays. It appears from the diagram that the drop in the amount of water required is greatest between 200 and 300° with most clays, although there are two exceptions in which this occurs at a higher temperature.

Owing to the fact that, independent of the slight variations in the molding, the amounts of shrinkage and pore water and hence

the exterior volumes of the test pieces were not proportionately constant during these experiments, it was decided to express the volume shrinkages in terms of the true clay volume, i. e., the weight of the dried clay divided by its specific gravity, as has been shown before.

The decrease in volume shrinkage thus expressed is shown for the 14 clays examined in Figs. 5 and 6.

The red-burning clays, it is observed, show four types of materials. The first class, represented by No. 1, the excessively plastic material from Fort Pierre, N. Dak., which resembles bentonite in its behavior, evidently stands for abnormal clays, clearly beyond the limits of the workable kinds. It shows an abrupt decrease in the shrinkage curve, beginning at 250°, and continues to lose at a somewhat diminished rate up to the maximum temperature employed. Its final shrinkage still remains so high that no mistake is made by calling this clay hopeless from the standpoint of its commercial use.

In the second class again only one material is represented, No. 13, a reddish-burning clay of the type of the so-called No. 2 fire clays. Its shrinkage loss curve is gradual, being most marked between 350 and 400°. This material being more homogeneous in structure and higher in clay matter than the average red burning clay seems to lose its plasticity more gradually, which differentiates it sharply from the other clays.

The third class of clays includes the average, highly plastic and frequently "sticky" clays of glacial or alluvial origin. The material losing its plasticity most abruptly is from an alluvial deposit. In practically all of them the most significant change took place between 250 and 300°.

In the fourth class we find one fine-grained material of glacial origin, evidently very high in nonplastic matter, which behaves very much like the other clays of the third group, differing only in its low initial shrinkage. It likewise seems to undergo its greatest change between 250 and 300°.

All of the clays, after showing their greatest drop in shrinkage, appear to change in color, assuming a reddish tinge and at the same time become granular. Finally, excepting clay No. 1, they

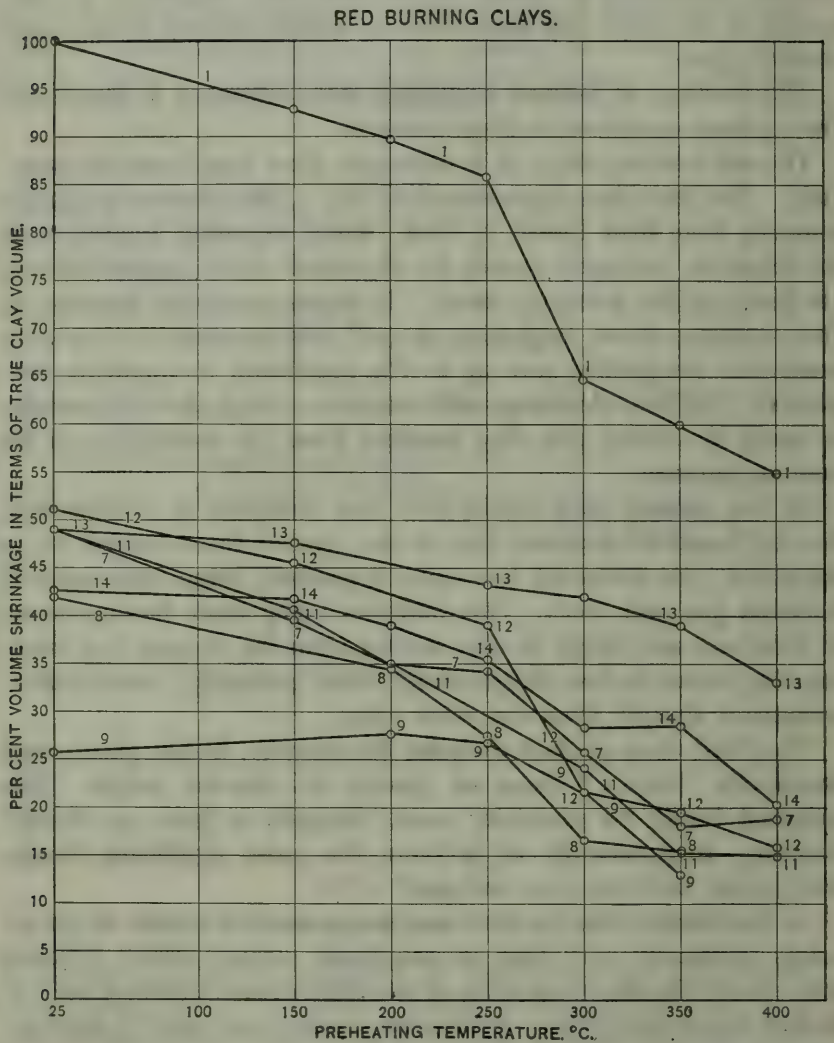

Fig. 5.—*Volume shrinkage of red burning clays, preheated to different temperatures, made again plastic with water and dried at 60° C.*

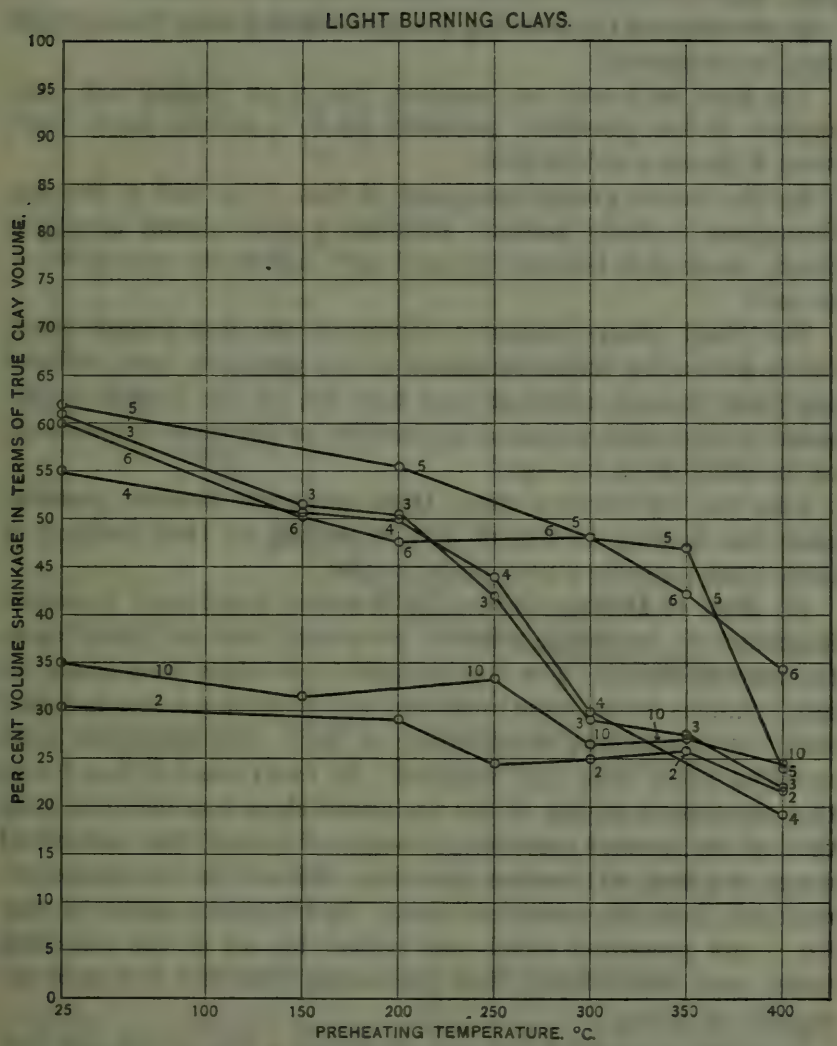

Fig. 6.—*Volume shrinkage of light burning clays, preheated to different temperatures, made again plastic with water and dried at 60° C.*

appear to be sand like and more or less inert in the presence of water. Up to 350° the absorption of water takes place with great eagerness and a sensible amount of heat is evolved.

In the diagram representing the light-burning clays three groups may be recognized:

The first, with only one member, No. 5, an English ball clay, appears to lose plasticity gradually up to a certain point, 350°, when it shows a sudden drop.

In the second group, composed of Nos. 3, 4, and 5, the loss throughout is fairly gradual, although a more abrupt change is clearly observable between 250 and 300°, and in the case of No. 6, at 300°.

The third group evidently comprises the less plastic clays, which with a low initial shrinkage do not appear to have suffered any great changes, although even here No. 10, the English kaolin, seems to have been impaired in plasticity at the same temperature as the other clays, 250–300°.

Like the red-burning clays, these materials become granular after the heating treatment and, according to their content of ferric oxide, assume a pink or gray color.

(b) **Rate of Drying.**—From the practical standpoint it seemed important to determine whether preheating had any effect upon the rate of drying. For this purpose eight clays were made up into cylinders of the same initial size and dried in a water-jacketed oven, at a constant temperature of 60°. The specimens were removed every hour and weighed. In every case it was found that the rate of drying of the preheated clays was identical with that of the normal materials, though, of course, the amount of water required to develop plasticity differed in the preheated materials from the normal amount. In Fig. 7 the curves of clay No. 1 are presented which are typical for all of the materials tested and show clearly that preheating does not influence the rapidity of drying.

In order to establish the rate of drying a clay in the raw and the preheated state under conditions permitting only of slow evaporation, a 200-pound sample of so-called swamp clay, very difficult to dry, was used. One-half of the sample was made up into 3.5-inch cubes on a small auger machine in the raw condition.

The other half was preheated to 250° C. before being made up into test pieces of the same dimensions. Of these, three cubes made from the raw and three from the preheated clay were selected and placed in a closet, maintained at room temperature,

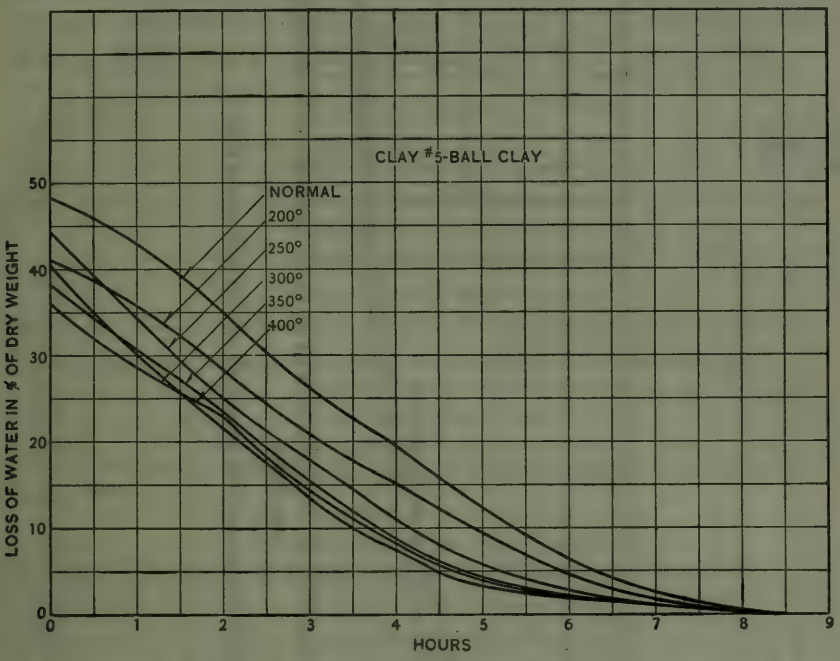

Fig. 7.—*Rate of drying of clay, preheated at different temperatures, again made plastic wtih water and dried at 60° C., compared with rate shown by the untreated clay.*

as close together as possible and their weights determined at intervals. In Fig. 8 the curves representing the loss of water of these specimens are shown, and it is seen that the rate of evaporation of the preheated clay approaches closely that of the raw material.

6. THE PRACTICAL EFFECT OF PREHEATING

In the experiments just described it has already been shown that preheating has decreased the drying shrinkage. From this it might fairly be assumed that clays should dry more easily in the preheated than in the raw condition.

Experimental proof of this fact was obtained by working up batches of about five hundred pounds each of seven clays, both

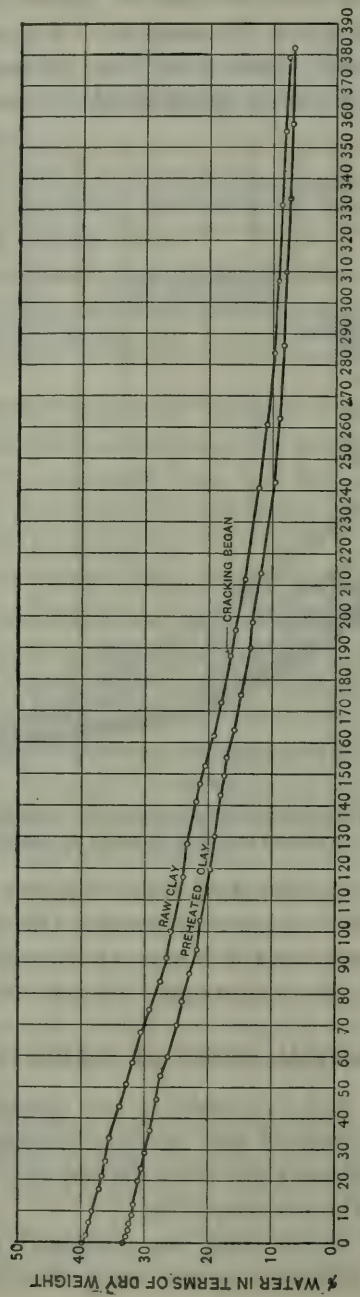

Fig. 8.—*Rates of drying of 3½ inch cubes pressed from normal clay and clay preheated at 250° C.*

in the raw and in the preheated condition to the plastic state and putting them through an auger machine of commercial size. The clays were of the red burning type as employed in brick making, and were obtained from the following localities: Albert Lea, Minn., Heron Lake, Minn., Urbana, Ill., Peoria, Ill., Groveport, Ohio, Athens, Ohio, and a so-called swamp clay from Curtice, Ohio.

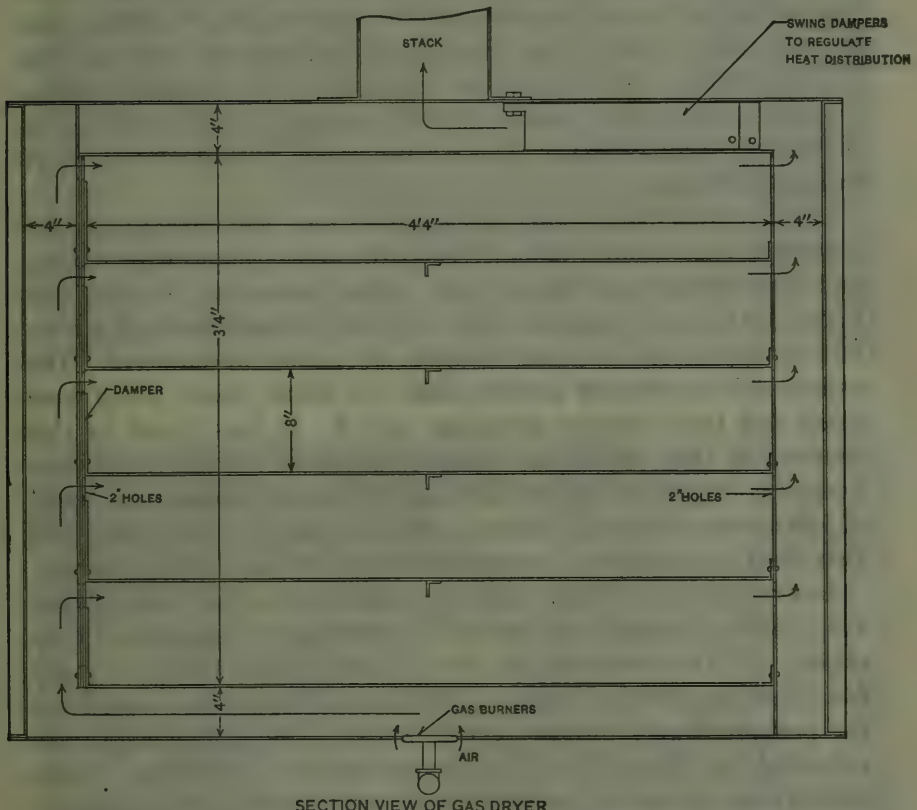

Fig. 9.—*Diagram of gas-fired drying oven used for preheating larger quantities of clay.*

The clay samples were preheated in a specially constructed sheet-iron oven fired with gas (Figs. 9 and 10), in which the heat distribution permitted of close regulation. This is accomplished by carrying the gases under the bottom plate up a collecting space on one side, from which they are distributed to each compartment. The admission of the heated air to each space

is regulated by means of a grid sliding damper. At the exit sides of the oven the gases are again collected in a flue of the width of the oven and taken to the top, where they are removed through a central opening into the stack. In the double space on top through which the gases are removed, two hinged dampers are provided for throwing the heat to either side to compensate for the radiation losses on the front and back sides of the oven. Through tubulatures thermometers are inserted for controlling the temperature. After proper damper adjustment was made it was possible to keep the temperature constant within several degrees, assuring an accuracy ample for the purpose of the work. The preheating temperature adopted was 250° C and the time of drying six hours.

The raw clays were tempered in a wet pan, while the preheated materials were ground dry, screened through a piano-wire screen, and then made plastic in the pan. After tempering, the clay was taken to the auger machine (Fig. 11), and pressed through a non-lubricating die into a round column 3½ inches in diameter. The cylindrical bar was cut up into discs 1½ inches thick, which were dried and their volume shrinkage noted. It was found in this connection that while the working behavior of two clays was decidedly improved by preheating, the others showed the need of lubrication, which it was impossible to provide. The result was that the test specimens were produced under conditions of strain.

In drying, it was found that one material, the clay from Heron Lake, Minn., cracked neither in the raw nor the preheated condition. Of the remaining six clays, in every case the discs made from raw clay cracked more or less badly, while those made from the preheated clay did not crack at all. The drying losses are compiled in Table VI. The number of test specimens made varied from 60 to 100, and for this reason the percentages expressing the drying loss are not of equal value.

It was observed especially on two preheated clays, the ones from Peoria and Groveport, that drier efflorescence was quite marked. From this it would appear that preheating releases the soluble salts such as the sulphates of potash, soda, lime, and magnesia contained in the clay, which, on the evaporation of the water, are carried to the surface and give rise to the discoloration

Fig. 10.—*View of Preheating Oven.*

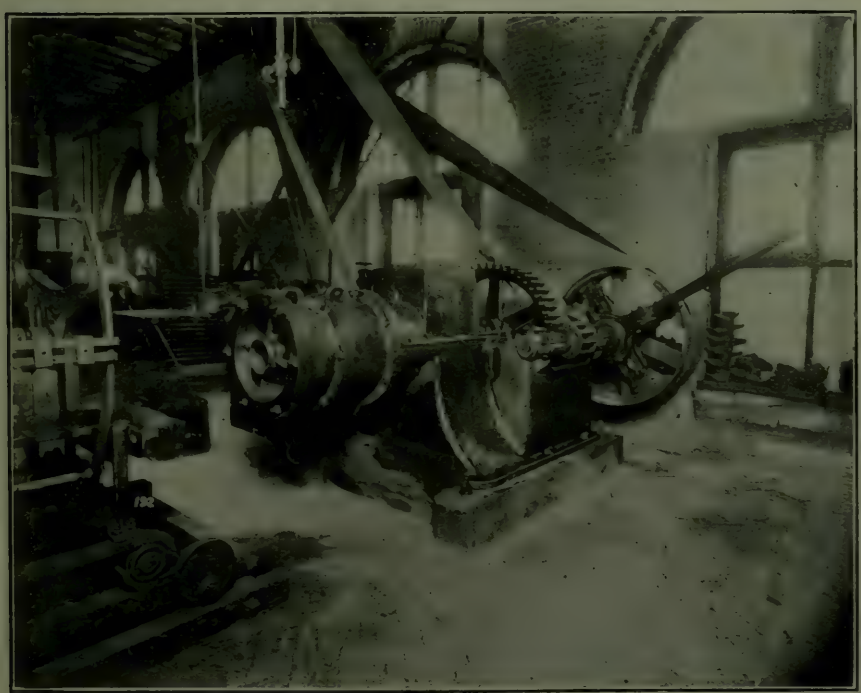

Fig. 11.—*View of Auger Machine*

commonly known as "white wash." The adsorbing power of clay thus seems to be diminished by this treatment, and in some clays the resulting discoloration might prohibit their use for the manufacture of face brick and similar products. It was evident, however, that this effect varied with the character of the clay, its physical structure, and its content of soluble salts, and hence can not be considered a necessary result in every case.

TABLE VI

Percentage Drying Loss

Clay	Per cent drying loss of test pieces made from raw clay	Per cent drying loss of test pieces made from preheated clay	Remarks
Albert Lea, Minn.	95	0	
Heron Lake, Minn.	0	0	
Urbana, Ill.	90	0	Repeated with clay preheated to 300°
Peoria, Ill.	95	0	Repeated with clay preheated to 300°
Groveport, Ohio.	100	0	Repeated with clay preheated to 300°
Athens, Ohio.	100	0	
Curtice, Ohio.	100	0	

7. THE CAUSE OF THE IMPROVEMENT IN THE DRYING BEHAVIOR DUE TO PREHEATING

It has thus been shown beyond doubt that the drying of excessively plastic clays is facilitated by preheating, that evidently the resistance to the capillary flow has been decreased so that the difference between the amount of water evaporated from the surface per unit time and that supplied from the interior of the clay mass is no longer great enough to cause strains which lead to checking.

There remains now the task of determining the cause of this improved condition.

This part of the problem was attacked by means of the following methods: 1. Determination of the specific gravity of the clays preheated to different temperatures. 2. Mechanical analysis of the normal and preheated clays. 3. Determination of the adsorbing power of normal and preheated clays from malachite green in solution. 4. Determination of the distribution of shrinkage and pore water.

Specific Gravity: In these experiments a pat of plastic consistency weighing about a pound was made up of each clay which was cut up into smaller lumps for preheating at the different temperatures. The preheating was done in the small drying ovens referred to above. The preheated specimens were then crushed and passed through a 60-mesh sieve. By means of the pycnometer the specific gravity of each sample was determined, care having been taken to eliminate the inclosed air by connecting up the specific gravity bottle to a suction pump and heating in warm water up to the boiling point. Ample time was allowed for cooling in running water and the final temperature of the liquid in the pycnometer was taken into account. It was found that the specific gravity of the clays differed even in the same lump, and it proved difficult to bring about the desired homogeneity of the sample. The results of these determinations are given in Table VII. Though the irregularity in the results is evident, it is

TABLE VII

Specific Gravity of Clays

No. Clay	Normal	150°	200°	250°	300°	350°	400°
1	2.451	2.456	2.630	2.603	2.603	2.657	2.621
2	2.537	2.548	2.636	2.612	2.609	2.644	2.647
3	2.577	2.591	2.600	2.600	2.590	2.593	2.590
4	2.596	2.589	2.646	2.629	2.629	2.664	2.664
5	2.560	2.560	2.550	2.605	2.601	2.600	2.600
6	2.510	2.512	2.562	2.545	2.556	2.580	2.573
7	2.510	2.490	2.648	2.638	2.627	2.653	2.665
8	2.603	2.621	2.653	2.650	2.655	2.692	2.696
9	2.784	2.741	2.728	2.725	2.721	2.747	2.751
10	2.476	2.560	2.605	2.639	2.638	2.637	2.644
11	2.575	2.587	2.649	2.650	2.645	2.676	2.697
12	2.680	2.707	2.709	2.729	2.769	2.732	2.696
13	2.768	2.739	2.701	2.761	2.820	2.825	2.773
14	2.645	2.666	2.684	2.712	2.662	2.743	2.708

seen that all but one clay show a noticeable increase in specific gravity due to preheating which must be ascribed in part to the expulsion of the small quantity of hygroscopic water held so persistently and in part to a condensation of the specific volume of the clay. Since it is not likely that the crystalline constituents have suffered any such change at the temperatures involved we must conclude that the effect is confined to the nongranular clay matter. The contraction in volume might be explained by the

closing up or shrinkage of the assumed colloidal matter very similar to the contraction of the silicic acid gel and other substances of like character. It is evident that this condensation would involve only the minute, micellean structure of the material and does not refer to the capillary system of the clay aggregate. In making up the preheated clays with water it was observed that some heat was given off. It was thought to be interesting to determine approximately the amount of heat thus evolved from a normally dried clay and a preheated material. For this purpose a sample of a red plastic surface clay was divided into two parts. One was dried at 105° C, the other was heated to 300°. By placing weighed amounts of the clay into an improvised calorimeter, adding a known amount of water and noting the temperature rise by means of a corrected thermometer reading to 1/50° the heat given off by the clay dried at 105° was found to be almost 4-gram calories and that by the preheated material practically 5 calories per gram.

Mechanical Analysis: In determining the changes brought about by preheating as regards the fineness of grain, four samples of clay were prepared by thoroughly mixing them and dividing each portion into two parts. One half was preheated to 300° C and then put through the Schulze apparatus, the other was run through in the normal condition. The results are compiled in Table VIII. In carrying out this work it became at once evident that the preheated clays showed an extraordinary tendency to form aggregate particles in spite of the fact that they were first mechanically shaken in water and apparently deflocculated by the use of NaOH and $Na_2C_2O_4$ solutions. These particles were found to be so hard that they could not be worked through the sieves by simple rubbing. The results show that for this reason the clays have become decidedly coarser, the surface factor having been decreased. This applies not only to the sieve sizes, but also to the sizes separated by the first two cans. This difference between the normal and the preheated clays appears to be due to coagulation, the fine individual particles forming aggregates of varying sizes. From this it follows that a decided change in the capillary structure of the clay must have been brought about tending either to increase or decrease the pore space. Just in what direction this change proceeds will be shown later.

TABLE VIII

Mechanical Analysis

NORMAL AND PREHEATED CLAYS

Clay	40	50	80	100	120	Cans			Overflow
						1	2	3	
N	0.84	1.77	1.33	3.78	0.20	8.02	15.12	2.21	66.72
G[1]300°	4.04	5.76	2.42	7.08	0.39	16.90	16.28	3.00	44.13
N	1.96	1.80	1.50	3.37	0.16	4.07	4.45	2.32	80.37
A[2]300°	4.56	2.66	1.96	1.33	0.22	5.47	8.38	5.01	70.40
N	1.11	1.37	0.58	0.70	0.15	2.79	26.56	5.07	61.66
S[3]300°	9.54	9.28	3.26	2.20	0.10	5.74	37.25	4.39	28.23
N	0.30	0.40	0.34	0.50	0.08	0.83	3.84	6.18	87.52
H[4]300°	3.71	2.77	0.71	1.99	0.33	3.29	5.57	4.44	77.17

[1] Alluvial clay, Groveport, Ohio. [2] Impure No. 2 fire clay, Athens, Ohio. [3] Joint clay, Urbana, Ill. [4] Glacial clay, Heron Lake, Minn.

Malachite Green Adsorption: H. E. Ashley[12] employs the ability of clays to absorb complex organic salts, such as malachite green, from their solutions as a means of comparing the plasticity of different clays, and makes the assumption that, other things being equal, the more plastic a clay the more of the dissolved substance it takes out of solution. In casting about for a numerical factor expressing the plasticity of a clay, however, he found it necessary to introduce two modifying factors, drying shrinkage and fineness of grain, as expressed by the Jackson-Purdy surface factor. He thus arrives at the expression:

$$P = \frac{C\,B}{A}, \text{ where—}$$

P = numerical value proportional to plasticity.

C = relative colloid content, based upon the amount of organic salt (malachite green) absorbed.

B = per cent shrinkage of clay discs made by casting the lawned slip into plaster molds.

A = surface factor.

Ashley hence assumes that plasticity is proportional to the amount of malachite green adsorbed from solution and to the drying shrinkage and inversely proportional to the fineness.

[12] Bulletin 388, United States Geological Survey.

Since in connection with the present work the fact that plasticity has been decreased by the preheating treatment has been established beyond doubt, it was thought to be of interest to determine the differences in the absorption of malachite green by preheated clays. This work was done by Mr. H. E. Ashley, and consisted in shaking one gram of clay by mechanical means in 100 cc of a malachite green solution containing 0.3 gram of the dye. The amount of malachite green remaining in solution was determined colorimetrically. The value thus obtained was then expressed as the relative adsorption capacity of the different materials in terms of the adsorption shown by a standard plastic clay, the Tennessee No. 3 ball clay. The latter was assumed, therefore, to show a colloidal value of 100. A clay giving a value of 75 should then contain 75 per cent of the colloid matter present in the Tennessee clay. The results of these determinations are compiled in Table IX.

TABLE IX

Adsorption Factors of Normal and Preheated Clays

Clay	Surface clay, Albert Lea, Minn.	Joint clay, Urbana, Ill.	Joint clay, Peoria, Ill.	Alluvial clay, Groveport, Ohio	Impure No. 2 fire clay, Athens, Ohio
Normal	600	142	175	104	160
Preheated at 250° C.	475	137	150	106	140

Inspection of these figures shows at once that, although in four out of the five cases the adsorption has been decreased, the difference is not in proportion to the difference in the physical behavior of the clays. It is evident, therefore, that, with the exception of the Minnesota clay, no decided change in structure is indicated by these tests. It would seem then that the partially irreversibly "set" gel shows the same adsorption as the reversible gel, and that the adsorption of malachite green, from its solution, does not appear to be any measure of plasticity, as far as these preheated clays are concerned.

Distribution of Shrinkage and Pore Water.—From the results of the mechanical analyses of the normal and preheated clays, as well as from direct observation made during the course of the

shrinkage experiments, it became evident that the amount of pore water in the preheated clays differed from that present in the normal materials. It hence was found necessary to determine the amounts of shrinkage and pore water present in the same clay after heating it to different temperatures. This was done similarly to the previous calculations of the drying shrinkage expressed in terms of the true clay volume. These results are collected in Table X.

TABLE X

Distribution of Shrinkage and Pore Water

Clay		Per cent by volume in terms of true clay volume.						
		Normal	150° C	200° C	250° C	300° C	350° C	400° C
Alluvial clay, Groveport, Ohio, No. 12.	Total water	87.20	80.52	71.11	73.00	72.60	74.60	70.80
	Shrinkage water	51.09	45.49	37.61	39.22	21.70	19.66	15.98
	Pore water	36.11	35.03	33.50	33.78	50.90	54.94	54.82
Glacial surface clay, Heron Lake, Minn., No. 13.	Total water	95.20	90.00	92.60	90.70	84.30	97.10	84.40
	Shrinkage water	42.65	41.80	38.92	35.37	28.27	31.17	20.35
	Pore water	52.55	48.20	53.68	55.33	56.03	65.93	64.05
Impure No. 2 fire clay, Athens, Ohio, No. 14.	Total water	72.19	78.06	73.17	70.33	75.78	71.60	71.88
	Shrinkage water	49.05	47.55	47.43	43.23	49.06	38.96	33.34
	Pore water	23.14	30.51	25.74	27.10	33.82	32.64	38.54

For the sake of facilitating comparison the relations obtained are shown graphically in Figs. 12, 13, and 14.

Referring to Fig. 12, it is observed that with this clay a marked increase in the amount of pore water is shown between 250° and 300°, and it is quite evident that the clay approaches the condition of an inert, nonplastic material as the shrinkage water decreases. The two curves will meet at the point at which the clay will have lost its plasticity. This increase in pore space shown brings out the fact that the preheating of clays causes them to become more porous, and it offers the explanation of the improved drying qualities of the materials thus tested. The increased pore space opens up the clay body, reduces the surface tension, and thus offers less resistance to the flow of water through the capillary system toward the end of the shrinkage when drying conditions are most severe. Owing to the smaller shrinkage it

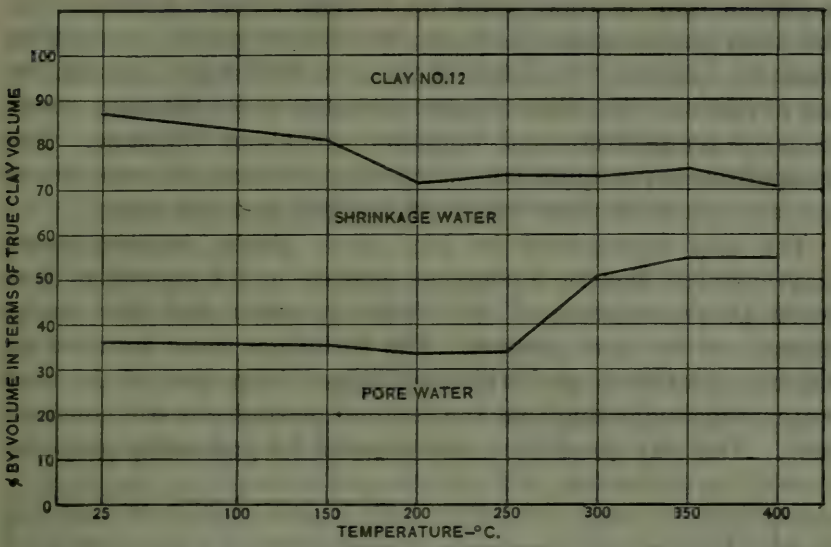

Fig. 12.—*Relation of shrinkage to pore water of Groveport, O., clay preheated at different temperatures, again made plastic with water and dried at 60° C.*

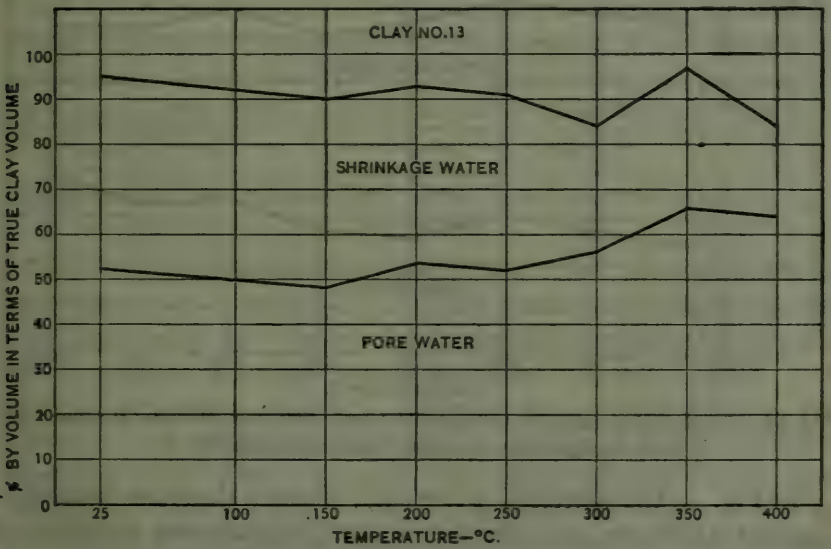

Fig. 13.—*Relation of shrinkage to pore water of Heron Lake, Minn., clay preheated at different temperatures, again made plastic with water and dried at 60° C.*

is evident that the total strain due to contraction is lessened. As has been shown above, however, the actual rate of evaporation from, for instance, two cubes of the same initial size, one consisting of raw and the other of preheated clay under the same conditions of temperature and humidity are about the same. This comparison is not quite fair, since the preheated clay cube would contain somewhat more weight of material than the other.

The clay represented by Fig. 13—a plastic, impure glacial clay—showed likewise a constant increase in the amount of pore water at the expense of the shrinkage water, but the change appears to be more gradual. The shrinkage water retained by the clay heated to 400° still constitutes a large part of the total water, thus indicating that the residual plasticity is still considerable. This clay should be a safe material for preheating purposes.

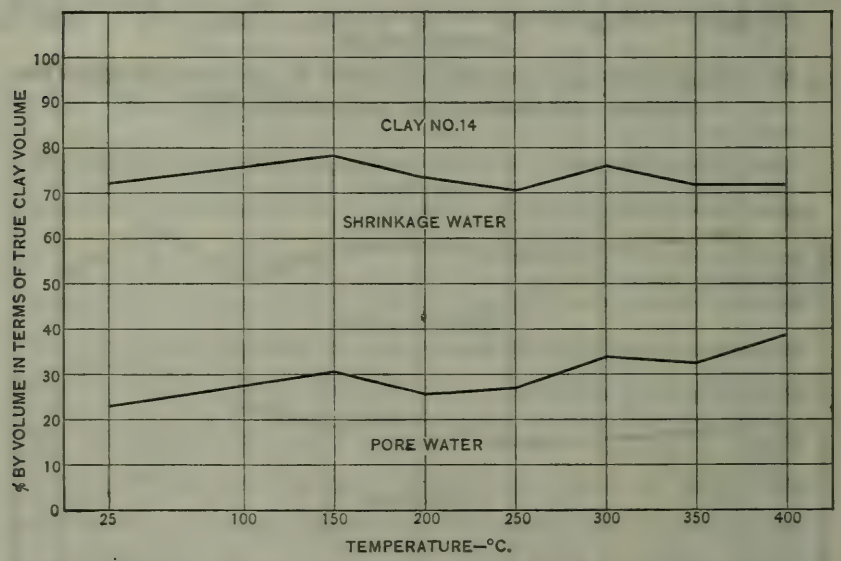

Fig. 14.—*Relations of shrinkage to pore water of Athens, Ohio, clay, preheated at different temperatures, again made plastic with water and dried at 60° C.*

In Fig. 14 the material, a fire clay, shows a decrease in shrinkage water between 300°–400° and a fairly high amount of shrinkage water at the highest temperature. It is evident that if preheating were necessary in this case the temperature could exceed 300°.

From these illustrations it appears that the proper preheating temperature varies for different clays. While in certain materials the desired change to a more nonplastic condition is brought about gradually it is abrupt in others. It is evident from this consideration that the permissible temperature range in the former case is considerably wider than for the latter, where an excessive temperature might carry the conditions too close to the inert state.

From the work done in the present study no general conclusions can be stated as to the behavior of all kinds of clay. As a broad proposition, it might be said that the more impure clays show as a rule a more abrupt change and more narrow temperature limits than the more homogeneous plastic clays of the No. 2 fire-clay or ball-clay types.

In regard to the time required for the preheating no attempt has been made to look into this matter, but it would appear from the present work that it is simply a question of transmitting the heat through the lumps of clay. The larger the average size of the clay lumps the longer should be the time allowed for the heating. From this it follows that it would be policy in commercial work to shred or cut up the material before introducing it into the drying apparatus. Under the conditions of practice the temperature of the rotary dryer is best maintained close to 500° C, and the time of passage through the dryer reduced accordingly.

8. THE EFFECT OF PREHEATING UPON THE MANUFACTURE OF CLAY PRODUCTS

Since it has been shown by experiment that the pore space of preheated clays increases as the clay particles gradually assume the character of more or less inert, sand-like matter, the question arises whether it might not be possible that some clays, even though preheated at lower temperatures, would become too porous to be worked successfully by certain molding machines used in practice, due to the fact that the permissible limit of pore water had been reached. Under this condition might it not be that owing to the greater average distance between the particles the cohesive force would not suffice to hold the mass together if a larger amount of water is used than is necessary to bring the clay to the condition in which it is used in auger machines?

This point was investigated by making up two preheated surface clays with a large amount of water to the consistency of the so-called "soft-mud" process and making them into bricks in regular wooden brick molds. It was found in both cases that the clays showed a decided tendency to "slump" and that they were too weak to withstand the drying strains, resulting in bad cracking and checking. The same preheated clays when worked on the auger machine dried without difficulty. This shows that the amount of water used in bringing such a clay to the plastic state must not be excessive. From this standpoint the auger-machine and dry-press process are to be preferred to the "soft-mud" method of molding.

In tempering preheated clay the point of proper stiff plastic consistency is defined more sharply than with the normal material. When the predried clay is worked in the auger machine it is important to provide the best lubrication it is possible to secure, in order that, owing to the decreased plasticity no strains are produced due to the flow of the clay through the die. The tendency to show auger lamination seems to be reduced by the preheating of the clay. Owing to the decreased drying shrinkage, the die or mold may be made smaller where common brick or other porous ware is to be produced. For vitrified products the gain due to the smaller mold size is slight, since, owing to the increased porosity of the dry clay, the burning shrinkage will be greater.

With reference to the burning of preheated clays it has been found that the combined drying and burning shrinkage, the burning being carried through vitrification, is less than in the case of the normal material. Clays differ in this respect, however. While in one instance the difference in the total volume shrinkages was but 1 per cent, in others it was very much greater. In one case the difference amounted to 12.4 per cent, expressed in terms of the dry volume.[13]

For products to be vitrified the factor of the greater porosity in the dried condition may enter into consideration. Since in vitrification the pore space is more or less gradually closed up, due to the softening of the clay, it is evident that the contraction in the apparent volume of a piece of clay ware must be practically

[13] A. V. Bleininger and F. E. Layman, Trans. Am. Ceramic Society, 11, pp. 354–365.

equivalent to the pore space of the dried material. The extent to which such a volume shrinkage may take place without injury to the structure, distortion, etc., is evidently limited. While, for instance, a brick made from shale, with an initial compact, dense structure may be vitrified without an excessive contraction during burning, a plastic surface clay, of loose structure on being carried to vitrification will suffer a far greater shrinkage, and hence is much more subject to defects brought about by the contraction in volume. If this clay were now to be preheated at a temperature at which its pore-water content is increased decidedly, it is clear that the difficulty referred to would be accentuated. For instance, referring to Fig. 12, it is reasonable to suppose that this clay when preheated to 300° would likely be troublesome in burning it to vitrification. On the other hand, the clay represented by Fig. 14, under the same conditions, would in all probability behave very similarly to its condition in the normal state.

From this it follows that some plastic clays, while they may be corrected as to drying behavior by preheating, might crack or check in burning, due to excessive burning shrinkage. The effect of the preliminary drying thus must be determined for each clay, and in any case the preheating must be carried on at the lowest temperature which suffices to overcome the drying defects. In some cases the admixture of normal and preheated clay might be satisfactory.

In practice the preliminary drying is undoubtedly carried on most efficiently in rotary dryers, such as are now in common use in the Portland-cement industry. The cost of the treatment in well-constructed dryers of this type is estimated to vary from 10 to 15 cents per ton of bank clay under the conditions obtaining in the Middle West, including labor and depreciation. This extra cost no doubt is a burden which should not be assumed where the clay can possibly be made to dry satisfactorily by other means, such as the addition of sand, weathering, etc. But where no other material is available and clay products are in demand, owing to lack of timber and stone, or where, as has been found in the case of an Illinois joint clay,[13] even the addition of sand does not overcome the tendency to crack in drying, the treatment offers a pos-

sible solution of the difficulty. Five instances are at present known to the writer in which preheating has been found to be the means of overcoming the poor working and drying qualities of certain clays, as has been proved by tests on a large scale.

At the same time it must be remembered that the dry clay can be disintegrated and screened more readily than the clay coming wet from the bank, thus enabling the manufacturer to remove the impurities, such as gravel, limestone, pebbles, and other mineral detritus, which are especially liable to be present in the glacial clays, more cheaply and thoroughly, besides making the operator independent of weather conditions. Also, it is thus possible to produce wares of a higher grade from low-grade material and in districts where other clays are lacking.

9. SUMMARY

The plasticity of clays is decreased by heating at temperatures above 100° C. This change becomes more marked with higher temperatures and is accompanied by reduction of the drying shrinkage upon reworking. According to the nature of the clay, the change proceeds abruptly after reaching a certain temperature or is more or less gradual throughout. A decided alteration seems to occur in most clays between 200° and 300° C, as is shown by the granular appearance of the clay and the decrease in the drying shrinkage. The color also becomes darker, and in ferruginous materials assumes a reddish hue.

The purer clays seem to be affected more gradually by this heat treatment.

The rate of drying of the preheated clays does not seem to differ from the rate for the undried clays.

Excessively plastic clays, which dry difficultly and result in loss due to checking and cracking, behave normally in drying after being preheated. The best temperature for this treatment must be determined for each clay, and invariably the lowest possible temperature giving the desired result should be adopted. Some preheated clays seem to release their soluble salts more easily than the normal materials. Such clays are likely to show dryer efflorescence.

Clays thus treated should be tempered with as little water as possible and require good lubrication.

The cause of the improved drying quality of the preheated clays is to be sought in the increased porosity. It appears that coagulation of the flocculent portion and the fine, nongranular particles of the clay takes place, analogous to the set of certain gels.

The combined drying and burning shrinkage of preheated clays (burnt through vitrification) is less than that of the normal materials. In most cases the drying shrinkage is decreased at the expense of the burning shrinkage, which becomes greater than the normal contraction. In some clays the increased porosity in the dried state may cause the burning shrinkage (if carried through vitrification) to be excessive, in which case the product will show checking or cracking in burning. Such clays, unless their objectionable features in drying can be eliminated by preheating at a low temperature, are not benefited by this treatment.

Preheating offers a possible commercial method for the treatment of excessively plastic clays which can not be worked and dried successfully by other means, subject to the limitations outlined above.

WASHINGTON, December 6, 1910.

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OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 2

THE STRENGTH OF REINFORCED CONCRETE BEAMS; RESULTS OF TESTS OF 333 BEAMS

(FIRST SERIES)

BY

RICHARD L. HUMPHREY
AND
LOUIS H. LOSSE

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PREFACE

The investigations herein reported were made by the Technologic Branch of the United States Geological Survey at the Structural Materials Testing Laboratories, St. Louis, Mo. When this work was transferred to the Bureau of Standards July 1, 1910, this manuscript was transmitted for publication.

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I. INTRODUCTION

The field covered by the United States Geological Survey's investigations was so large that the work, for convenience, was divided into several groups. The first group embraces the strength of concrete beams without reinforcement at ages 4, 13, 26, and 52 weeks, of which all except the 52-weeks' tests have

been reported in Bulletin 344[1] covering the properties of concrete, the relative values of various types of aggregates, and the influence of a variation in consistency or an increase in age on their strength and elasticity and the uniformity attainable in tests of this character.

The tests herein reported cover what is probably the simplest and most readily interpreted failure of reinforced concrete in flexure, viz, where the unit stress exceeds the yield point of the reinforcement.

The materials entering into the tests herein described were generously supplied by the following-named companies:

CEMENT

Atlas Portland Cement Co., Hannibal, Mo.
Edison Portland Cement Co., Stewartsville, N. J.
Illinois Steel Co., Chicago, Ill.
Iola Portland Cement Co., Iola, Kans.
Lehigh Portland Cement Co., Mitchell, Ind.
Omega Portland Cement Co., Jonesville, Mich.
St. Louis Portland Cement Co., St. Louis, Mo.
Virginia Portland Cement Co., Fordwick, Va.
Whitehall Portland Cement Co., Cementon, Pa.

STEEL

Illinois Steel Co., Chicago, Ill.

CRUSHED STONE, GRAVEL, AND CINDERS

Fruin-Bambrick Construction Co., St. Louis, Mo., crushed limestone.
Schneider Granite Co., St. Louis, Mo., crushed granite.
Union Sand & Material Co., St. Louis, Mo., gravel.
United Railways Co. of St. Louis, St. Louis, Mo., cinders.

SAND

Union Sand & Material Co., St. Louis, Mo.

For services rendered in the work of computing and compiling the data on which this bulletin is based acknowledgment is made to Harry Kaplan, William A. Camphell, E. B. Tolsted, and Norman De Witt Betts, assistant engineers, United States Geological Survey.

[1] U. S. Geological Survey.

II. PURPOSE OF TESTS

These tests form a part of the study of the behavior of reinforced concrete beams under load, as influenced by the character of the concrete, and the arrangement and percentage of reinforcement.

III. SCOPE OF TESTS

The scope of tests is outlined in the following table:

TABLE 1

Concrete				Number of Test Pieces				Half-inch Round Bars Mild Steel [2]			Variables
Mortar		Aggregate	Consistency	Beams	Cylinders	Cubes	Bond [3]	Per cent	Number of Bars In Beam	Number of Bars Tested	
1	2	4									
Typical cement	Meramec River sand	One set each with limestone, gravel, granite and cinders	Medium	48	48	48	One set of 12 for each aggregate	0.49	2	96	Aggregate age and percentage of reinforcement
				48	48	48		.74	3	144	
				48	48	48		.98	4	192	
				48	48	48		1.24	5	240	
				48	48	48		1.47	6	288	
				48	48	48		1.72	7	336	
				48	48	48		1.96	8	384	
Total.....				336*	336	336	48			1680	

[2] Elastic limit steel approximately 40,000 pounds.
[3] Detail tests to be published in separate paper.
* Three of these beams were not tested.

The series consisted of 336 beams, together with the corresponding cylindrical and cubical test pieces for compression tests, and 48 bond test pieces to determine the adhesive strength of the aggregates used: Representative material of each of four classes of aggregates, gravel, crushed granite, crushed limestone, and cinders, were used in making up the test pieces, which were tested in triplicate at the ages of 4, 13, 26, and 52 weeks, respectively.

The report of these tests has been confined exclusively to a presentation of test data in such a way as to indicate with considerable certainty the various elements which affect the design

of architectural and engineering structures. Studies have therefore been made near maximum load between external load conditions, as measured by the bending moment, and resistance of the beam as determined by the resisting moment. There is included the relation between the unit stress at maximum load and the yield point of the reinforcement.

Studies have been made for maximum load and for unit stresses of 16 000 and 32 000 pounds of the relation between the effective percentage of reinforcement and (1) the resistance of the beam as measured by $\frac{M}{bd^2}$, (2) percentage depth to the neutral axis, (3) unit compressive stress in the extreme upper fiber, (4) the deflection at the center of the beam. The results are presented diagrammatically and in greater detail in tabular form.

The change of such relation with age and the difference due to the nature of the aggregate have also been determined and are presented in the following pages.

The development and spacing of the tension cracks below the neutral axis for the various aggregates, ages, and percentages of reinforcement is plainly shown by photographs of the beams.

There is also included a study of plain concrete in direct compression. The growth in strength with age and the increase in stiffness, as measured by the initial modulus of elasticity, are clearly brought out. The variation with age of the ratio of the yield point to the ultimate strength for the different aggregates has been determined.

No extended discussion of the theory of reinforced concrete is attempted in this bulletin and theoretic formulas have been introduced only where necessary for the intelligent presentation of the data. The formulas used are, however, not original with this bulletin but are based on assumptions which are thought to approximate the truth.

IV. TESTS OF THE CONSTITUENT MATERIALS

1. CEMENT

The cement used in all the tests in these laboratories is known as typical Portland cement. It is prepared by thoroughly mixing together a number of Portland cements. The method of prepar-

ing the typical Portland cement that was used in the tests herein reported was as follows:

One thousand eight hundred sacks of cement, 200 from each of nine companies, were used. Two hundred sacks of one brand were spread over a concrete floor 25 by 40 feet in area and thoroughly mixed by hoeing from side to side. Two samples were then taken, a 50-pound sample for tests to be made by the constituent-materials section, and a smaller one for chemical tests. The cement was then resacked. When all the brands had been separately mixed in this way two sacks of each brand were spread on the floor in a layer about 3 inches thick. One brand was spread upon another in blanket form, making nine separate layers of cement for the nine brands used. The mass was mixed very carefully with shovels until a uniform mixture was obtained. A 10-pound sample was taken for physical tests and the cement was sealed in air-tight cans, two cans of 800 pounds capacity each being required to hold one mix.

Table 2 (p. 9) of the present bulletin contains the physical tests on the individual cans of cement which were used in the preparation of all concrete reported in this bulletin. The samples of cement on which these tests were made were taken at the time the typical Portland cement was prepared, just before the individual cans were sealed.

2. SAND

The sand used was what is known as Meramec River sand and was identical with that used in the series of plain concrete beams reported in Bulletin 344.[4] The physical properties of this sand are given in Table 3 (p. 11).

3. AGGREGATES

With the exception of the cinders the aggregates used were practically identical with those used in the concrete beams reported

[4] U. S. Geological Survey.

Table 2.—Physical Properties of Cements Used in First Series

Reg. No.	Specific Gravity	Temperature, Fahrenheit		Water, Per Cent	Time of Set, Minutes				Fineness of Residue on Sieve		Tensile Strength, Age in Days					
					Vicat		Gilmore				1	7	28	90	180	360
		Water	Air		I	F	I	F	100	200						
387	....	...	...	20.75	240	445	285	480	5.25	21.75	375	669	747	875	695	...
392	3.165	75.2	87.0	21.00	130	298	213	365	5.20	21.50	402	685	814	774	723	793
397	3.162	80.0	95.0	21.00	140	299	236	366	5.00	21.65	460	711	722	780	748	779
399	....	...	...	21.00	193	385	252	480	5.10	21.60	277	665	735	899	748	...
400	....	...	...	21.00	193	406	257	483	5.30	21.75	277	656	721	807	754	...
402	3.163	79.0	86.0	21.00	161	310	227	379	5.20	21.65	416	689	811	783	827	803
406	3.165	79.0	86.0	21.00	157	310	225	385	5.00	21.60	427	659	828	795	809	823
419	3.165	79.0	86.0	21.00	177	310	239	393	5.00	21.40	440	688	741	790	789	802
427	3.166	77.0	85.0	21.00	168	342	221	397	5.50	22.00	447	691	790	797	813	803
443	3.164	79.0	86.0	21.00	...	310	230	387	4.90	21.50	427	685	786	791	776	832
451	3.164	75.2	87.0	21.00	137	303	211	366	5.45	22.80	416	690	795	784	799	823
453	3.163	77.0	82.0	21.00	142	305	282	358	5.25	21.70	460	675	751	778	778	814
456	....	77.0	85.0	21.00	188	343	226	395	...	....	455	695	690	779	843	778
463	....	...	...	21.00	...	335	247	455	5.55	21.75	224	641	727	876	770	...
478	3.157	75.2	87.0	21.00	134	303	210	369	5.00	21.80	422	684	798	787	805	811
485	3.167	68.0	71.0	20.75	...	395	266	457	5.55	22.25	290	688	680	786	860	904
487	3.165	68.0	73.0	20.75	207	387	263	453	5.35	22.30	301	693	789	798	853	861
[5] 490	3.168	68.0	78.0	20.75	183	364	236	436	5.40	22.45	269	702	790	812	853	857

[5] In water and air warped one sixty-fourth of an inch around edge of pat.

Table 2.—Physical Properties of Cements Used in First Series—Continued

Reg. No.	Specific Gravity	Temperature, Fahrenheit		Water, Per Cent	Time of Set, Minutes				Fineness of Residue on Sieve		Tensile Strength, Age in Days					
		Water	Air		Vicat		Gilmore				1	7	28	90	180	360
					I	F	I	F	100	200						
492	3.162	80.0	89.0	21.25	148	336	230	406	...	....	451	695	783	779	748	753
[6] 493	3.172	78.8	92.0	21.00	133	276	204	346	5.15	20.95	450	698	786	769	772	883
494	3.167	80.6	94.0	21.00	103	267	191	....	5.20	21.60	420	724	759	746	754	752
498	3.160	77.0	95.0	21.00	125	285	202	346	4.80	21.30	460	671	754	760	756	791
501	3.172	80.6	98.0	21.00	127	277	204	346	4.85	21.60	465	672	763	771	778	820
503	3.163	80.0	85.0	21.25	142	296	217	352	5.10	21.65	431	692	753	757	740	819
504	3.163	77.0	89.0	21.00	135	287	194	335	...	....	455	655	775	762	790	814
513	3.165	68.0	71.0	20.75	...	382	271	466	5.30	22.20	321	684	802	813	863	871
516	....	68.9	89.0	20.75	155	339	214	383	5.40	22.35	326	673	784	807	863	898
518	3.163	80.0	85.0	21.25	160	335	264	413	4.80	22.50	468	679	702	765	767	800
519	3.166	80.0	89.0	21.25	162	334	230	411	5.01	20.90	440	686	753	778	744	813
520	3.165	79.0	82.0	21.00	164	379	247	440	5.30	22.65	453	676	775	773	763	788
[7] 523	3.160	68.0	73.0	20.75	208	405	282	454	5.30	22.40	311	690	774	827	865	854
526	3.165	68.0	78.0	20.75	...	344	239	429	5.40	22.35	287	697	799	797	860	910
Ave..	3.165	75.8	85.0	20.97	160	334	235	404	5.19	21.86	391	683	765	794	791	823

[6] Steam warped one thirty-second of an inch around edge of pat.
[7] Air warped one sixty-fourth of an inch around edge of pat.

in above bulletin, Table 6, page 17. While the cinders were obtained from the same source as those previously used they came in a different car and were therefore treated as a separate sample. The physical tests on all the aggregates are given in Table 3.

Table 3. —Physical Properties of Sand and Other Materials Forming Aggregates Used in Beams

Kind of Material	Specific Gravity	Percentage of Voids, Computed	Weight, Pounds Per Cubic Foot	Percentage Passing Sieve or Screen				
				200	100	80	50	40
Cinders	1.750	.....	.....	2.35	3.24	3.87	4.90	5.87
Granite	2.585	40.90	95.30	1.59	2.29	2.62	3.22	3.74
Gravel No. 1, Beams 333 to 388	2.450	33.00	102.40	0	0	0	0	0
Gravel No. 2, Beams 389 to 416	2.479	.....	.....	.....	.....	.....	.....	.....
Limestone	2.489	37.10	97.70	2.96	3.48	3.70	4.18	4.68
Meramec River Sand No. 1, Beams 162 to 197	2.597	37.90	100.60	.20	1.30	3.60	13.90	37.00
Meramec River Sand No. 2	2.619	33.89	107.91	.20	1.94	6.09	24.11	43.90

Kind of Material	Percentage Passing Sieve or Screen							
	30	20	10	¼ inch	½ inch	¾ inch	1 inch	1½ inches
Cinders	7.10	9.13	14.15	21.58	77.06	93.23	96.50	100.00
Granite	4.38	5.45	8.50	19.88	57.54	99.25	99.71	100.00
Gravel No. 1, Beams 333 to 388	0	0	.95	43.00	79.30	95.20	98.50	100.00
Gravel No. 2, Beams 389 to 416	.....	.....	.....	.....	.....	.....	.....	.....
Limestone	5.23	6.21	10.69	28.71	60.56	96.04	99.37	100.00
Meramec River Sand No. 1, Beams 162 to 197	64.00	81.50	97.00	100.00	.....	.....	.....	.....
Meramec River Sand No. 2	60.28	74.64	88.96	100.00	.....	.....	.....	.....

4. REINFORCEMENT

The maximum load carried by a beam of given dimensions, which is insufficiently reinforced to develop failure by compression and in which the concrete is sufficiently strong to prevent failure by bond or diagonal tension, is proportional to the percentage and to the yield point of the reinforcement. The failure in this case will be caused by the unit stress in the reinforcement exceeding the yield point. If for a given percentage of reinforcement the yield point is low the maximum load carried will also be low as compared with that carried by a beam containing reinforcement having a higher yield point.

In order, however, to establish a consistent relation between the maximum load carried and the percentage of reinforcement, and in order to study the effect of the yield point of the reinforcement on the carrying capacity of the beam, the yield point of all the reinforcement used in a given beam should be identical. If the yield points of the reinforcement used in a given beam vary widely the failure of the beam, instead of being due to the simultaneous failure of all the reinforcement, will be caused by the failure in detail of the reinforcement. The coefficient of elasticity of the reinforcement being independent of the yield point, all the bars in the beam will elongate equally for a uniform, well-bedded vertically and axially loaded beam, for all stresses below that corresponding to the lowest yield point of the reinforcement in the beam. When this lowest yield point has been reached this particular bar will elongate much more rapidly and under a practically constant unit stress, thereby throwing much more of the load on the remaining bars. One would expect, therefore, that the increment of the elongation of the reinforcement for the same increment of load will now be greater than it was when the unit elongation was less than the lowest yield point of the reinforcement.

For bars of different yield points in the same beam the elongation curve of the reinforcement will suffer a change of direction as each bar fails, the curve becoming flatter as the load increases. Where there is considerable difference in the yield point of the reinforcement and for high percentages of reinforcement, this progressive flattening begins at some load prior to maximum load. If the yield point of the bars used is, however, practically identical,

the increments of deformation of the reinforcement should be proportional to the increments of load almost to the maximum load.

In order, therefore, to compare the maximum loads carried by identical beams or to study the effect of a change in the percentage of reinforcement the yield point of the reinforcement used in all the beams of a series should, as far as possible, be identical.

The reinforcement supplied to the laboratory was mild steel of presumably 55 000 to 65 000 pounds ultimate strength. It was thought, however, that in the steel as shipped there would be a greater variation in the yield point than should be permissible in a series of tests which it was hoped would furnish data for the conclusive investigation of reinforced concrete. It was therefore necessary to test a coupon from each bar to be used and then classify the steel according to the yield point.

(a) METHODS OF TESTING REINFORCEMENT

All the steel was tested, using the following method:

After the diameter of the 16-inch coupon had been determined at several points along its length and averaged, two punch marks were made, exactly 8 inches apart. The test piece was then placed between the flat wedges of the grips so that there was a space of about 1½ inches between the punch marks on the test piece and the ends of the wedges. The surface of the steel around the lower punch mark was then whitened with a soapstone pencil. As the load was being applied one operator pivoted one point of a pair of dividers (whose points were firmly clamped 8 inches apart) in the upper punch mark and drew a line on the whitened surface of the steel at the other punch mark. As the steel elongated uniformly below the yield point a series of parallel lines was drawn by the lower divider point, their distance apart for equal load increments being approximately the same. To aid in distinguishing between these lines a magnifying glass was used. Near the yield point a sudden increase was noticed in the distance between these lines for the same increment of load. The unit stress in the steel at that point has been designated "elastic limit (by dividers)." At a somewhat higher unit stress there was a more or less sharp drop of the scalebeam. This unit stress has been called the "yield point." The "ultimate strength" is the maximum unit stress in the steel. The unit stress based on the load at rupture

and the original cross section has been called the "breaking strength."

After rupture the character of the fracture, whether silky or granular, was noted and the average diameter of the "neck" calipered. The pieces were then placed together and the percentage elongation read from a special rule. From the measured diameter of the neck the reduced cross section was determined, and the difference from the original cross section was calculated. The ratio of this difference to the original area has been called the "reduction in area."

(*b*) RESULTS OF TESTS OF REINFORCEMENT

The average results of the tests of the reinforcement in each beam have been compiled in Table 4 (p. 121).

Examining the values in column 6 it will be seen that the ultimate strength varies between 52 000 and 64 000 pounds, with the majority lying between 55 000 and 60 000 pounds. The steel therefore corresponds to what is known as "mild" steel.

The elastic limit by dividers varies between 33 000 and 41 000 pounds while the yield point lies between 35 000 and 43 000 pounds. The steel was classified on the basis of the elastic limit, each group differing by 2000 pounds.

The group 37 000 to 38 000 would be limited by unit stresses of 36 500 and 38 499 and similarly for all groups. The steel was first classified on this basis, but it was noticed that the values obtained for the elastic limit were subject to much more variation than was the case for the yield point. This was due to the fact that the operators found great trouble in fixing definitely the point at which the rate of change of the distance between the closely drawn parallel lines on the surface of the steel would change.

In all steel classified subsequently, the groups were based on the yield point, which, for mild steel at least, is a very definite point and independent of any personal equation of observation.

The average tests on reinforcement compiled in this table represent 1260 tests and furnish ample data for the study of the relation between the various qualities reported.

An examination of this table will show that for even the same or practically identical ultimate strengths there may be considerable variation in the elongation and in the reduction in area.

A considerable difference is noticeable in the yield point of steel having the same ultimate strength, the difference in some cases being as much as 5 000 pounds per square inch.

The change in the yield point and the ultimate strength do not necessarily go hand in hand, an increase in the ultimate strength not always being accompanied by an increase in the yield point.

A rough comparison showing the variation of the various qualities with a change in the ultimate strength can readily be made, and is summarized below:

Table 5.—Effect of Changes in Ultimate Strength of Reinforcement

(MILD STEEL)

Elastic Limit (Pounds Per Square Inch)	Yield Point (Pounds Per Square Inch)	Ultimate Strength (Pounds Per Square Inch)	Percentage Elongation in 8 Inches	Percentage Reduction in Area	Number of Tests Averaged
36 100	38 600	53 400	30.1	72.5	10
39 400	41 100	60 900	28.2	59.7	12
37 300	44 000	72 800	23.6	53.0	5

In comparing the values in these tables, however, it should be borne in mind that the extreme variation in the value of the ultimate strength occurs within comparatively narrow limits and that the tests were made on coupons tested just as they were cut from the bar and not on turned test pieces.

V. DETAILS OF TESTS

1. DESCRIPTION OF TEST PIECES

(*a*) BEAMS

The beams, 13 feet long, 8 by 11 inches in cross section, were tested on a 12-foot span by two equal loads applied at the third points. The cross sections of the various beams, giving the horizontal and vertical spacing of the reinforcement are shown in Fig. 1.

The reinforcement throughout consists of one-half inch round bars having a yield point of approximately 40 000 pounds. The percentage of reinforcement was varied by changing the number of bars. For all percentages above 1 the size of the beam

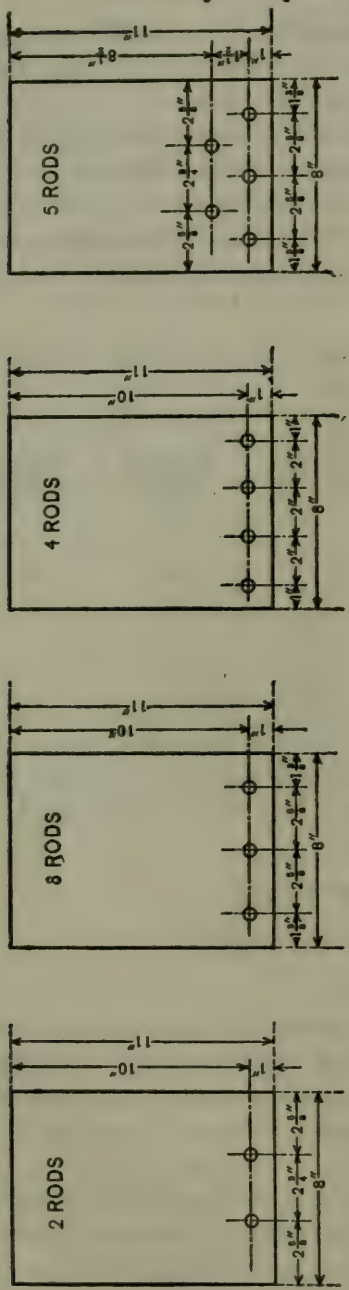

Fig. 1.—*Distribution of Reinforcement*

used made it impossible to place the reinforcement in a single layer. For these percentages the reinforcement was therefore placed in two layers, the depth from the top of the beam being 8½ inches to the center of the top layer and 10 inches to the center of the bottom layer. The "nominal" percentages of reinforcement 0.5, 0.75, 1, 1.25, 1.50, 1.75, and 2, corresponding to 2, 3, 4, 5, 6, 7, and 8, one-half inch round bars respectively were based on the cross section of the beam above the lower layer of bars. The percentages thus obtained are not, however, the effective percentages that determine the resistance of the beam. The method of obtaining the "effective" percentages will be described in detail later.

(b) COMPRESSION TEST PIECES

The cylindrical test pieces were 8 inches in diameter by 16 inches in length while the cubes were 6 inches on the side.

(c) BOND TEST PIECES

For the bond test pieces a one-half inch round bar was embedded on the axis of a cylinder (8 inches in diameter and 6 inches in length) so that one end projected one-fourth inch beyond the cylinder and the other end projected sufficiently to permit gripping it in the jaws of the testing machine.

2. METHOD OF MAKING TEST PIECES

(a) PROPORTIONS

A 1 : 2 : 4 volume proportion was adopted for all the concrete used in the following tests. Since, however, the volume of a given weight of dry sand is greatly affected by the percentage of moisture present, it was thought best to do the actual proportioning by weight. The weight of 1 cubic foot of cement was assumed to be 100 pounds. The weight per cubic foot of the dry, loose sand and the dry, loose aggregate as determined by tests in the constituent-materials laboratory, was used in reducing the proportions by volume to the proportions by weight.

With this as a basis, the necessary weight of dry material for the desired batch was determined. Since the sand and stone, as stored in the bins, contained an appreciable amount of moisture, the dry weight of the material had to be increased by the weight of the moisture present before the batch could be weighed out.

The percentage of moisture was determined on a 500-gram sample of the sand and stone representing as nearly as possible an average of the material in the bin and this was then maintained constant.

(*b*) MIXING

All concrete was mixed in a motor-driven cubic-yard cube mixer, equipped with a charging hopper. All water used in mixing concrete was weighed and supplied to the mixer through a hose attached to a water barrel, mounted on a platform scale on a support above the mixer. To insure uniform conditions the interior of the mixer was wet down each morning before the first mix of the day. All concrete was mixed two minutes dry and three minutes wet, after which it was dumped on the cement floor, shoveled in wheelbarrows and wheeled to the molding floor. Sufficient material was charged into the mixer to make three beams, three cylinders, and three cubes from the same batch of concrete.

In order to eliminate the personal equation as far as possible, the amount of water required to bring the batch to the desired consistency for a particular aggregate was carefully determined by trial before the test pieces were molded. Thereafter the weight of water to be used with each aggregate for that consistency could be obtained by making a simple correction, depending upon the percentage of water contained in the aggregate as it came from the bins. The total amount of water, including moisture, was expressed as a percentage of the total weight of the dry material and was maintained constant.

Concrete of medium consistency had a smooth appearance in the mixer, but showed a tendency to lump. When dumped, it stood in a pile with steep slopes, exhibiting a somewhat lumpy appearance and showing individual stones, but no voids. The stones showed an even coating of mortar. No water collected on the surface of the beam in the mold. The surface was easily finished with a trowel.

(*c*) MOLDING

The beam molds consisted of three long steel channels with flanges turned outward, forming the sides and bottom of the mold.

The ends were closed by short pieces of channels. The side and end pieces were removable. The molds were oiled before the concrete was placed, to prevent adhesion to the surface of the steel. In molding reinforced concrete beams two methods were used, depending upon whether the reinforcement was placed in one or two layers.

Where the reinforcement was in one layer it was placed 1 inch from the bottom of the beam. Sufficient concrete was first placed in the bottom of the mold to bring the surface of the layer a little above the center of the reinforcement. After this layer had been tamped once with a hand tamper, the reinforcement was placed upon it and held in the proper position by slotted wooden templets. The reinforcement was then tamped down into the concrete the required depth; the distance from the top being gauged by means of a T-shaped templet, the arms of which rested on the top of the sides of the mold and the end of the leg on the reinforcement. The concrete was then placed in three equal layers, each layer being tamped once, then spaded back from the surface of the mold and tamped again. The tamping was done by a pneumatic tamper working under 60 pounds pressure and having a 3 by three-fourths inch rectangular head.

Where the reinforcement was in two layers the manner of placing the first layer of concrete and the bottom layer of reinforcement was identical with that followed when there was but one layer of reinforcement. When the lower layer of reinforcement had been placed a layer of concrete was added of such a thickness that, when tamped, its surface came almost to the depth of the center of the upper layer of reinforcement which was placed 2½ inches from the bottom of the beam. This layer of reinforcement was then placed in the same manner as the first layer. The concrete in the remainder of the beam was placed in three layers in the usual manner and the top troweled.

The molds were removed at the end of 24 hours and the beams covered with burlap until, at the end of from two to three weeks, they were moved into the damp closet. Both before and after being placed in damp closet they were sprinkled every eight hours. The temperatures on the molding floor and in the damp closet were maintained as near 70° F as possible.

3. METHODS OF TESTING TEST PIECES

(*a*) BEAMS

The method of testing reinforced beams has been described in a previous bulletin[8] but it is thought best to repeat some of this information for the purpose of facilitating the study of the results.

Fig. 2 shows a reinforced beam under load with all the attachments. The construction of the box girder, through which the load is transmitted to the beam, and the deformeter are fully described in Bulletin 329.[8] While the gauge length, 29.25 inches, was the same as that used in the tests on plain beams, the vertical spacing of the contact points was different, the upper point being 0.5 inch below the top, while the lower one was placed 1 inch above the bottom of the beam on the plane of the lower layer of reinforcement. By this arrangement the elongation of the reinforcement in the lower layer was read directly, no error due to the reduction of the readings from one horizontal plane to another being possible. The only source of error with this arrangement would be the irregularity in the vertical position of the reinforcement and on the assumption that the elongation read by the micrometers is the uniform lengthening of the reinforcement in the gauge length, uninfluenced by the incasing concrete and free of any comparatively large local elongations where the reinforcement spans a crack in the concrete.

Since the upper contact point is placed 0.5 inch below the top surface of the beam it does not record the exact total deformation of the extreme outer fiber, at which crushing will first appear. With the usual arrangement of deformeters in which the contact points are clamped against the sides of the beam this is the only method possible and it therefore becomes necessary to reduce the readings of the upper micrometer to the outer fiber, making the usual assumption of conservation of plane section.

The deflections were read directly to the nearest 0.005 inch by a wire fastened at each end of the beam, at a point 4 inches below the top surface, and passing in front of a mirror and scale fastened to the center of one face of the beam. The scale was graduated to 0.01 inch, but by reading always the same part of the top or bottom

[8] U. S. Geological Survey.

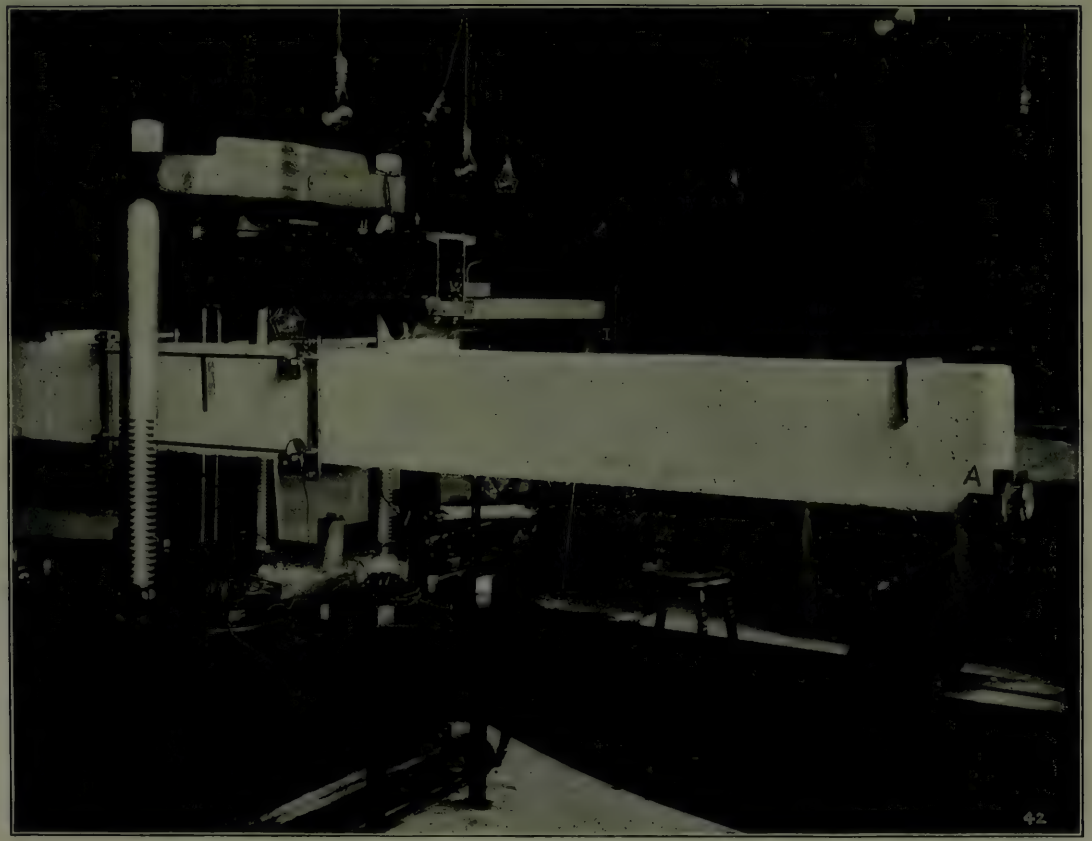

Fig. 2.—*Beam with Electric Contact Deformeters*

of the wire when it coincided with its image in the mirror 0.005 inch could be easily and accurately measured.

In order to measure any slip that might occur between the end of the reinforcement and the adjacent concrete, a stirrup (Fig. 3) was clamped to the beam, with the contact points in the plane of the reinforcement. This stirrup carried a micrometer screw reading directly to 0.0001 inch, which bore against the smoothed end of one of the reinforcing bars in the lower layer. Since if a slip occurs it is usually an appreciable quantity the readings for these micrometers were thought sufficiently accurate if read by manual contact, and consequently no electric circuit was used.

The electric-contact deformeters were used on all beams with the exception of a few of the 13 and 26 week tests on which Johnson deformeters (Fig. 3) were used. In this type of instrument the rod extending from one yoke to the other is pivoted at one end similarly to that for the electric-contact deformeters. To the other end of the rod is fastened a slip of metal, which rests lightly on a small drum fastened to a little shaft, to one end of which a pointer is attached. One end of the pointer carries a vernier which travels along a circular scale on the circumference of a dial in which the pointer moves. By means of the vernier, deformations can be read to 0.0001 inch.

In order to trace the development of cracks on the surface of the beam it was necessary to examine it with magnifying glasses. In examining the surface of the beam within the gauge length it was almost impossible to avoid disturbing the rods extending across the surface from one deformeter yoke to another. In the case of the Johnson deformeters this was a very serious matter, for any movement or jarring of the rod would result in a permanent movement of the indicating pointer over the face of the dial so that the reading of any dial in this case would be the legitimate movement due to the deformation of the concrete between the contact points, plus or minus the movement caused by any disturbance to the rods.

A disturbance of the rods where the electric-contact deformeters were used made no material difference, since a reading of the micrometers could be only taken when the end of the micrometer screw bore against the end of the rod and caused the closing of an

electric circuit. After this reading was taken the screws would, in any case, be turned back a little, in order to prevent the end of the micrometer screw jamming against the end of the rod when load was being applied. What happened to the rod between readings was comparatively unimportant; provided, always, that the fixed end of the rod was always pressed home snugly and the free end returned to its position in the grooved roller when being replaced.

When, therefore, the surface of the beam was being examined for cracks the lower rod would be removed, and replaced when more load was being applied.

The method of "zero moments" described in detail in Bulletin 344 [9] was used on the reinforced beams. While this method seems warranted for the deformations it has no rational basis for the deflections. Since, however, the deflection curve for loads below that which causes the concrete to crack on the tension side is practically a straight line the position of the deflection due to the weight of the beam could be estimated on this assumption with but little error.

While in the majority of cases load increments of 1000 pounds were used throughout the greater part of a beam test, no arbitrary set of loads was adopted and used. The increments of load applied were determined largely by the aggregate and percentage reinforcement as well as the behavior under load. In all cases the attempt was made to so choose the loads that the greater number of points would be obtained where the deformation curves suffered a change of direction. Such points would occur when the beam first commenced cracking and for some little time after that, depending on the percentage of reinforcement. Near maximum load and particularly for the higher percentages of reinforcement and the weaker aggregates the deformation curves would in many cases again change their direction, making a greater number of points desirable in order to accurately define the curve.

In some cases, with the low percentages of reinforcement in the four-week tests, the increments of load were as low as 250 to 500 pounds while for higher percentages and greater ages 1000-pound increments could be used throughout.

[9] U. S. Geological Survey.

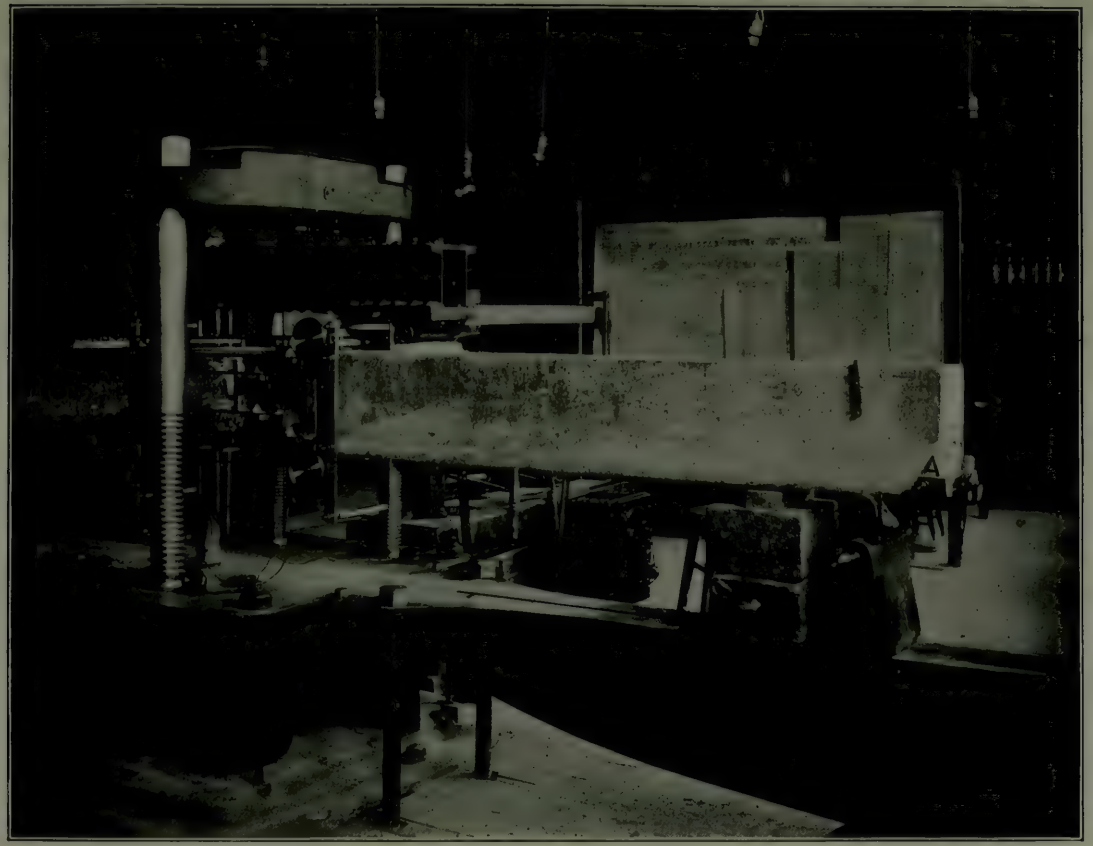

Fig. 3.—*Beam with Johnson Deformeters*

In the earlier tests, in order to more definitely fix the load at which the first crack appears, the surface of the beam was examined after the application of each increment of load succeeding that at which the rate of change of the deformations was seen to increase. It was soon noticed, however, that a beam at this stage could not be permitted to rest under load for the time necessary to hunt for cracks, since a noticeable flattening of the deformation curves would occur due to this rest. In order to prevent this the surface of the beam was examined only after each 1000-pound increment during this period of the test, although deformations might have been read for every 250 or 500 pounds. In many cases there is, therefore, an apparent discrepancy between the loads at which the first crack appears in three identical test pieces. If the development of cracks is traced only after each 1000-pound increment of load and in one case a crack appears between 2750 and 3000 pounds load, while in another identical test piece it occurs between 3000 and 3250 pounds, in the first instance the first crack would be recorded at 3000 pounds, while in the latter it would be reported for 4000 pounds. Under these conditions a total maximum apparent discrepancy of nearly 1000 pounds could be reported.

The frequency with which the development of cracks was traced was governed entirely by the behavior of the beam under load. If it was noticed that the cracks increased in height very slowly between successive load increments, cracks would be traced every other load or even less frequently if the case would warrant it.

The endeavor was made in each case to trace the essential development of the cracks but not every detailed change. It is not possible to obtain a detailed history of the development of the cracks and an accurate set of deformation readings from the same beam, since, in order to trace the cracks, the beam must remain under load for a considerable time and the deformation readings are consequently affected.

For each increment of load there were four micrometers to be read. It was desirable to read these simultaneously at all times but particularly so near maximum load to eliminate the effect of rest on the concrete for those beams that failed by compression, and in order to obtain the exact elongation of the reinforcement

for those that failed by tension to compare it with that corresponding to the yield point.

When, therefore, the rapid increase of the readings of the upper micrometers indicated the proximity of a compression failure, these were read first while, if the elongation of the steel approached that for the yield point, the lower micrometers were not only read first but read continuously as the load was applied. This was made necessary by reason of the fact that, when approaching maximum load, the elongations are increasing regularly, the increment of deformation being proportional to the increment of load. At the instant that maximum load is reached, there is a sudden sharp drop of the scalebeam and a correspondingly sudden large increase in the elongation of the reinforcement. This behavior necessitates reading both lower micrometers simultaneously and continuously and recording the last reading previous to the sudden increase in the deformation.

The time required to take the four micrometer readings and the deflection varies from 30 to 45 seconds so that the effect of rest between the separate micrometer readings may be considered negligible.

As the cracks developed their course was traced with a lead pencil on the surface of the beam, a short line being drawn across the crack at the point where it became invisible. At this point the applied load at that particular time is marked on the beam. After testing, the beams (piled in groups of three identical test pieces, with the cracks and numbers marked with black paint) were photographed. These photographs, giving a complete history of the development of the cracks, are shown in Figs. 22 to 30, facing page 96.

(*b*) COMPRESSION TEST PIECES

The cylinders and cubes are tested on a four-screw 200 000-pound machine. To insure an even distribution of load over the entire cross section the ends of the cylinders are bedded in plaster of Paris to a thickness of about one-half inch on a piece of plate glass (previously oiled to prevent adhesion of the plaster). The bearing surfaces are made normal to the axis of the cylinder by means of a spirit level applied to its sides. The cubes are not

capped with plaster of Paris, but a thin piece of asbestos is placed on a spherical bearing plate when under test, in order to take up all nonparallelism of the ends.

The load is in each case carried to failure, being applied continuously to rupture in the case of the cubes and in increments of 5000 pounds, or approximately 100 pounds per square inch, for the cylinders. For each increment gross deformations are read on two opposite sides of the cylinder over a gauge length of 12 inches.

4. METHODS OF COMPUTATION

(a) BEAMS

Throughout this Bulletin a "parabolic formula" has been used in discussing the resistance of reinforced concrete to flexure. This was thought necessary, as it was desired to have a close agreement between the external bending moment, based on the loading and dimensions, and the internal resisting moment, based on the stresses and position of the neutral axis. In the formulas used, the character of the deformation curve of the concrete in compression is determined by the percentage of the ultimate compression deformation which has been developed for that particular concrete in the beam under discussion. Even if there were but little difference in the stress deformation curve in compression for different materials (which is not the case), the varying percentages of reinforcement used in the beams develop widely different compressive deformations at maximum load and consequently different distribution of the compressive stresses. For working stresses, the differences are probably small. For some of the beams one would expect considerable variation in the results obtained with different assumptions as to the distribution of the stress, particularly those with the higher percentages of reinforcement and all the cinder concrete. While it would have been very desirable to use the actual percentage of the ultimate compressive deformation that was developed in each beam in the computations, the large number of beams to be reviewed made necessary the assumption of some average stress deformation relation, to be kept constant throughout all computations. It was therefore assumed that one-half the ultimate deformation of the concrete in compression

was developed in the upper fiber of the reinforced concrete beams. For independent analysis of the results of this series, the logs of the tests are given on pages 142 to 200.

The symbols and the formulas used in these tests are the same as those used in Bulletin No. 4 of the University of Illinois Engineering Experiment Station[10] and their derivation will therefore not be repeated here. The formulas there given, however, are applicable only to reinforcement placed in one layer and the modification necessary to adapt them to reinforcement in two layers will therefore be given.

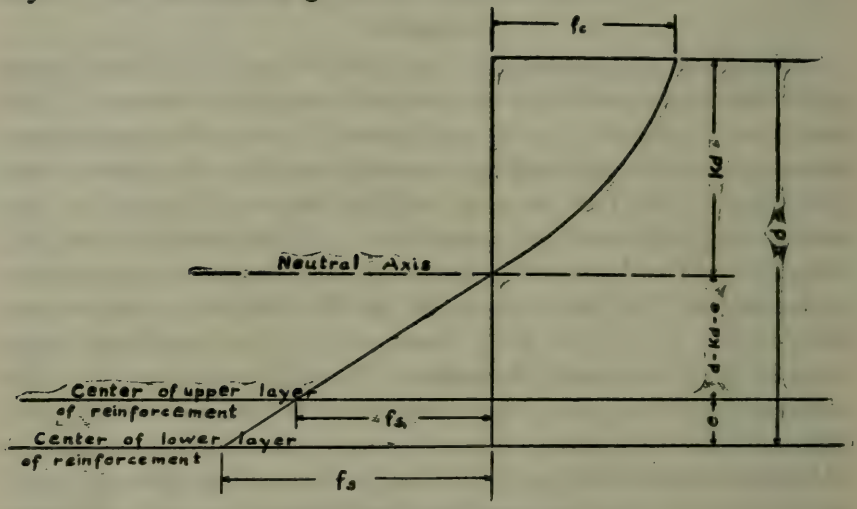

Fig. 4.—*Illustration of Symbols*

(1) Definition of Symbols Used.—

b = breadth of beam, in inches.

d = depth of beam, in inches, to center of lower layer of reinforcement.)

e = distance, in inches, between center of lower and center of upper layer of reinforcement.

z = distance, in inches, from top of beam to the center of gravity of the compressive stresses.

[10] Talbot, A. N., Tests of Reinforced Concrete Beams, Series of 1905, University of Illinois Bulletin, vol. 3, No. 14, 1905.

(1) **Definition of Symbols Used**—Continued.

Kd = distance, in inches, from the top of the beam to the neutral axis. (The distance is obtained directly from the measured deformations of the concrete and the reinforcement.)

A = total area, in square inches, of reinforcement in lower layer.

A_1 = total area, in square inches, of reinforcement in upper layer.

q = ratio of the unit compressive deformation of the concrete developed in the beam for any given load to the ultimate compressive deformation of that concrete.

m = number of bars in lower layer of reinforcement.

o = circumference of each bar.

Σ_o = sum of circumferences of all bars.

p = "nominal" percentage of reinforcement based on the area of the concrete above the center of the lower layer of steel.

f_s = unit stress in lower layer of reinforcement.

f_{s1} = unit stress in upper layer of reinforcement.

f_c = unit compressive stress on extreme fiber of beam.

M = total bending moment or total resisting moment, in inch pounds.

V = total vertical shear in pounds.

u = bond stress per unit area of surface of bar.

The general formula for the resisting moment of beams containing but one layer of reinforcement expressed in terms of the unit stress in the reinforcement, and neglecting all tensile stresses in the concrete is

$$M = Af_s\,(d-z).$$

In Bulletin No. 4 above referred to it has been shown that z varies with the different assumptions made as to the shape of the stress deformation diagram for concrete in compression and with the magnitude of the stress. For a straight line stress deformation diagram for concrete in compression $z = \frac{1}{3}Kd$ while for $q = 1$, i. e., for a beam that fails in compression, $z = 0.375\ Kd$. For beams in which the compressive strength of the concrete is not

developed z lies between 0.33 Kd and 0.375 Kd. For our case q has been made equal to one-half and is kept constant throughout all computations.

(2) **Formulas for Reinforcement in One Layer.**—The formulas given in Bulletin No. 4 of the University of Illinois Engineering Experiment Station were used directly and are given below:

$$M = Af_s\,(d - 0.35\,Kd) \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$f_c = \frac{2pf_s}{K} \times \frac{1 - \frac{1}{2}q}{1 - \frac{1}{3}q} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$u = \frac{V}{om(d - 0.35\,Kd)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

for $q = \frac{1}{2}$, equation (2) becomes

$$f_c = \frac{1.8\,pf_s}{K} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

While equation (4) was used throughout all the computations it was thought advisable to give equation (2) from which it is derived. Whether a straight line stress deformation diagram or a parabola with the apex at the extreme fiber is chosen makes very little difference in the values of M or u. This is not the case, however, with the values of f_c. While for a straight line formula the resisting moment will differ but little from that when the parabola is used, the unit compressive stress for the former case will be 33 per cent higher than in the latter. This difference will become smaller and smaller as the ratio of the compressive deformation developed in a given beam to the ultimate compressive deformation of the concrete decreases. It should, therefore, be realized that the unit compressive stress in the extreme fiber of those beams having a high percentage of reinforcement, particularly for the cinders and perhaps the majority of the four week tests, may be as much as 20 per cent high.

With equation (2), however, any one who cares to do so can analyze the results using the actual values of q.

(3) **Formulas for Reinforcement in Two Layers.**—For any given distribution of reinforcement and a given fraction of the ultimate deformation of the concrete developed, the position of

the center of the compressive stresses is fixed. It has been indicated above that the variation in the position of the center of the compressive stresses, for varying intensities of stress in the concrete, is very small, and that the position as governed by this variable can be considered constant.

The theoretical influence on the position of the neutral axis of a distribution of the reinforcement in more than one layer has not been determined, since the position of the neutral axis that is used in the computations is determined directly from the measured deformations assuming conservation of plane section.

(4) Formula for Unit Stress in Lower Layer of Reinforcement.—If, then, we may consider the position of the center of compressive stresses as known for a particular case, we may write the following expression for the total bending moment at the center of the beam:

$$M = A_1 f_{s1}(d - 0.35\,Kd - e) + A f_s(d - 0.35\,Kd) \qquad (5)$$

Within the elastic limit of the steel

$$\frac{f_{s1}}{f_s} = \frac{d - Kd - e}{d - Kd}$$

Substituting this value of f_{s1} in (5)

$$M = \frac{A_1 f_s\,(d - 0.35\,Kd - e)\;(d - Kd - e)}{d - Kd.} + A f_s(d - 0.35\,Kd) \qquad (6)$$

This formula gives the unit stress in the lower layer of reinforcement, provided the elastic limit of the reinforcement is not exceeded.

(5) Formula for Unit Compressive Stress in Extreme Fiber of Beam.—For the reinforcement arranged in two layers equation (2) must be modified as follows:

The sum of all the tensile stresses is now $A_1 f_{s1} + A f_s$

but

$$\frac{f_{s1}}{f_s} = \frac{d - Kd - e}{d - Kd}$$

Making these changes in equation (2) we obtain

$$f_c = \frac{2 f_s [A_1 (d - Kd - e) + A\,(d - Kd)]}{Kbd\,(d - Kd)} \times \frac{1 - \frac{1}{2} q}{1 - \frac{1}{3} q} \qquad (7)$$

For the approximate formula $q = \frac{1}{2}$ we obtain

$$f_c = \frac{1.8 f_s [A_1 (d - Kd - e) + a (d - Kd)]}{Kbd (d - Kd).} \quad (8)$$

(6) **Formula for Unit Bond Stress.**—For the reinforcement placed in two layers, it has been proven (6)

$$M = \frac{A_1 f_s (d - 0.35\, Kd - e)\ (d - Kd - e)}{d - Kd} + A f_s (d - 0.35\, Kd)$$

Differentiating

$$\frac{\delta M}{\delta x} = \left[\frac{A_1 (d - 0.35\, Kd - e)\ (d - Kd - e)}{d - Kd} + A\ (d - 0.35\, Kd)\right] \frac{\delta f_s}{\delta x}$$

But $$\frac{\delta M}{\delta x} = V$$

Therefore

$$V = \left[\frac{A_1 (d - 0.35\, Kd - e)\ (d - Kd - e)}{d - Kd} + A\ (d - 0.35\, Kd)\right] \frac{\delta f_s}{\delta x} \quad (9)$$

But $$A\ \delta f_s = \Sigma_0 u \delta x$$

Therefore $$\frac{\delta f_s}{\delta x} = \frac{u \Sigma_0}{A}$$

Substituting this value of $\frac{\delta f_s}{\delta x}$ in equation (9) and solving for u

$$u = \frac{VA\ (d - Kd)}{\Sigma_0 [A_1 (d - 0.35 Kd - e)(d - Kd - e) + A (d - 0.35 Kd)(d - Kd)]} \quad (10)$$

If in equation (10) A_1 is made zero

$$u = \frac{V}{\Sigma_0\ (d - 0.35\, Kd)}$$

which is the formula for reinforcement in one layer.

(*b*) COMPRESSION TESTS

The compression tests reported in this paper were made primarily with a view of determining the elastic behavior and the ultimate strength of the concrete that was used in the correspond-

ing reinforced beams. While it was thought necessary to have the ultimate strength of the concrete as given by a compression test in order to compare with the computed extreme fiber stress of any beams that might fail by the compression of the concrete in the upper fiber, it is also thought extremely desirable to have a complete record of the elastic behavior of the concrete under pure compression. By comparing the extreme fiber stress, as computed from the bending moment for a given load, with the unit compressive stress for the same unit deformation of the cylinder, the relation between the behavior of concrete in direct compression and in compression in a beam may be established.

The stress deformation curve of the cylinders is further useful in determining the character of the stress deformation curve of the concrete in compression in the beam.

No study of the possible influence of the initial modulus of elasticity of the concrete upon the position of the neutral axis, as given by a theoretical formula, can be made, unless this quantity is observed in a compression test.

Considered apart from their value in aiding in the interpretation of the tests on the reinforced beams, these tests in themselves form a very complete investigation of the compressive strength of concrete.

For each age and aggregate 21 beams were molded, three each for seven percentages of reinforcement. For each beam one cylinder and one cube were molded, making 21 identical test pieces of each. It seems reasonable to believe therefore that the accuracy of any relations brought out by the average of such a large number of tests will have sufficient weight to warrant the almost self-evident conclusions that have been arrived at by a study of the present tests.

(1) **Definition of Terms and Symbols.**—While the significance of the terms and symbols used in these tests is similar to those used in other investigations, it is thought advisable to define them briefly here.

Weight in Pounds per Cubic Foot.—This was computed from the weight as obtained for the cylinder or cube as it was brought from

the damp closet and the volume as given by the measured dimensions.

Ultimate Strength.—The ultimate strength was obtained by dividing the maximum load carried by the test piece by the actual sectional area as given by the measured dimensions.

Initial Modulus of Elasticity.—This term is defined as the ratio of the unit stress to the unit gross deformation, as given by the ordinate and absiccæ of a point on a line drawn tangent to the initial part of the curve, or coincident with it when there is straight line variation. The direction in which this line is to be drawn is determined by eye on the plotted curve, the aim being to draw a straight line through as many points as possible even if by so doing it will not pass through the origin.

Yield Point.—At some unit stress, which differs with the material and age, the curve showing the relation between the unit stresses and the corresponding unit gross deformations will turn from the line of the initial modulus of elasticity. Below this point, which is herein called the "yield point, the unit stresses are directly proportional to the unit deformations.

Stress Ratio of Cylinders to Cubes.—This ratio is obtained by dividing the ultimate strength of the cylinders by the ultimate strength of the cubes.

VI. RESULTS OF TESTS

1. BEAMS

The complete log of all beam tests is given in Appendix II, page 142.

Some of the results of the tests of reinforced concrete beams are summarized in Tables 6 to 21, facing page 128, and typical curves are shown in Figs. 41 to 45.

It is not the aim of these tables to present the results of a detailed study of the tests, but rather the values that are usually used in the design of a beam. The greater part of each table has therefore been devoted to a comparison of the resisting moment with the bending moment, and the relation between the unit stress in the reinforcement at the failure of the beam and the yield point of the reinforcement used. The unit compressive stress in the extreme fiber of the beam, as figured from the bending moment

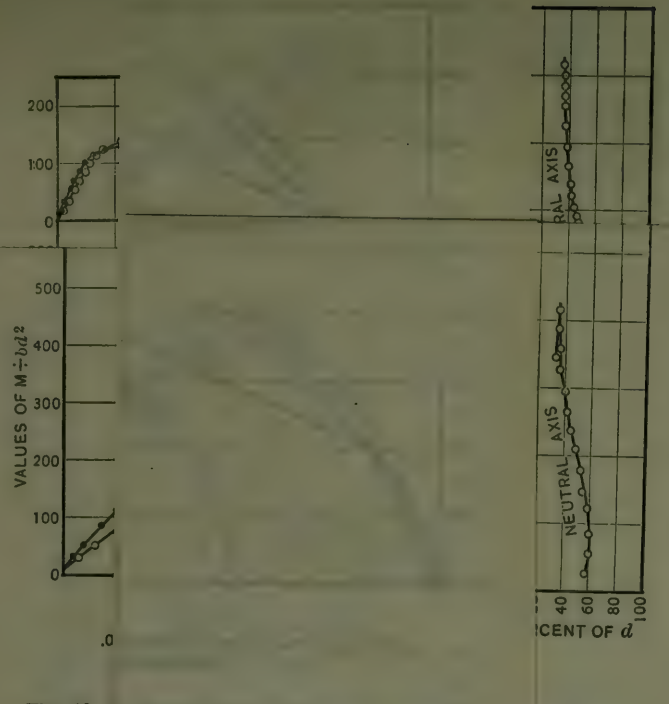

Fig. 43.—

ent, Ages 4

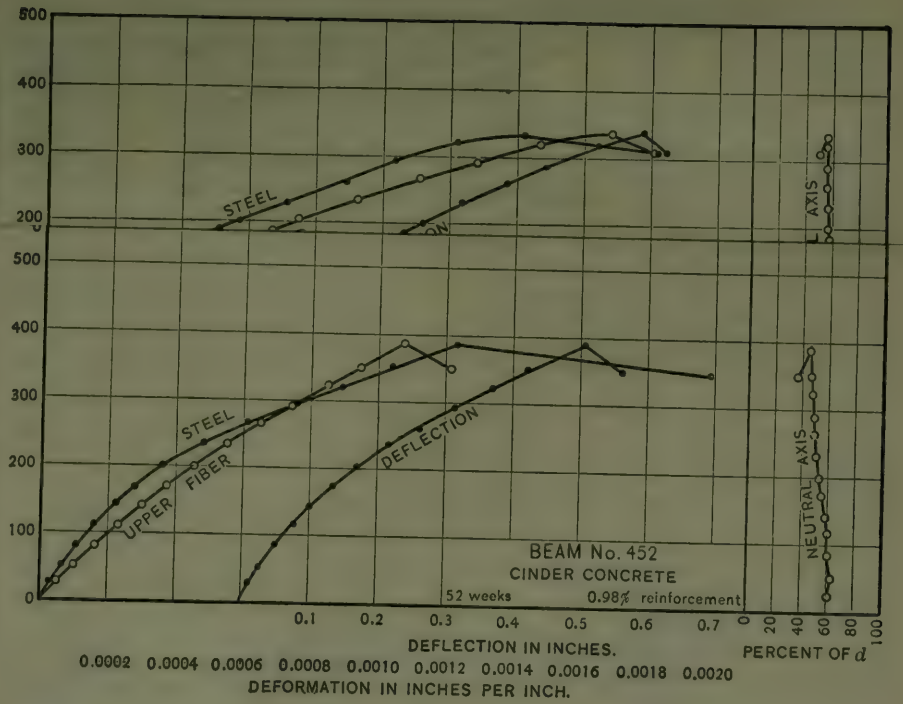

Fig. 42.—*Stress Deformation Curves of Cinder Concrete 0.98 per cent Reinforcement, Ages 4 Weeks and 52 Weeks*

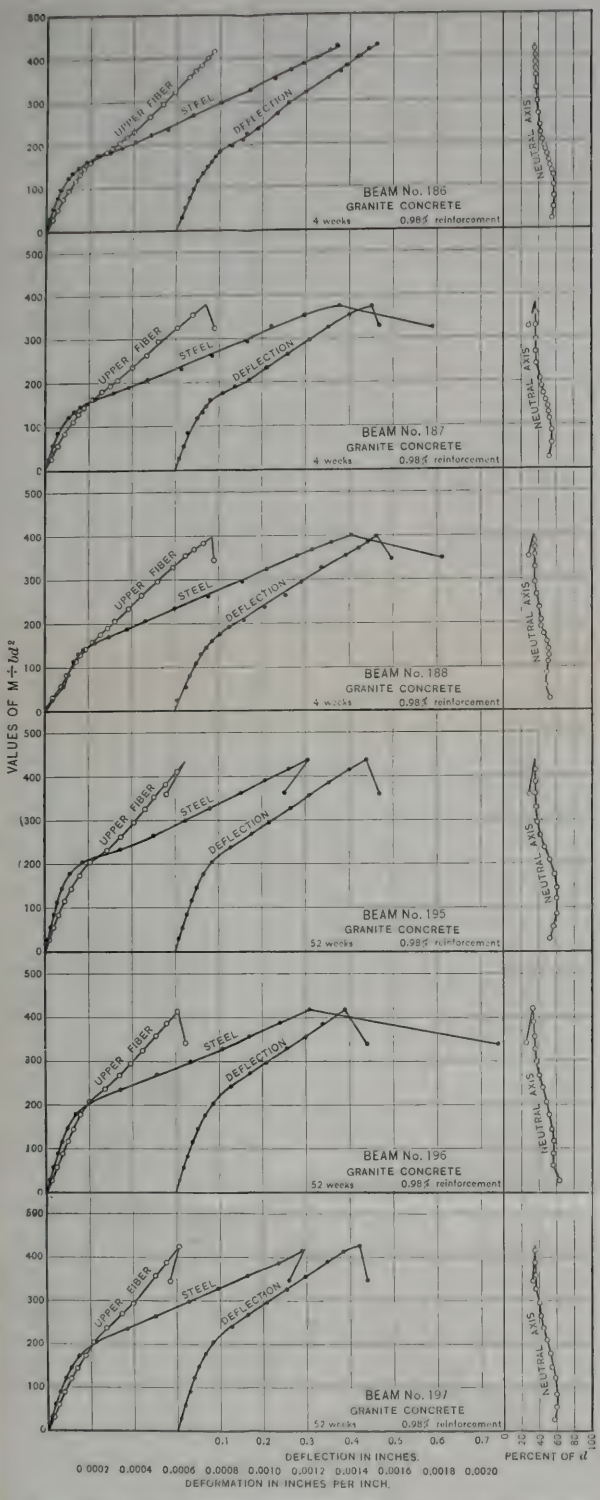

Fig. 41.- *Stress Deformation Curves of Granite Concrete 0.98 per cent Reinforcement, Ages 4 Weeks and 52 Weeks*

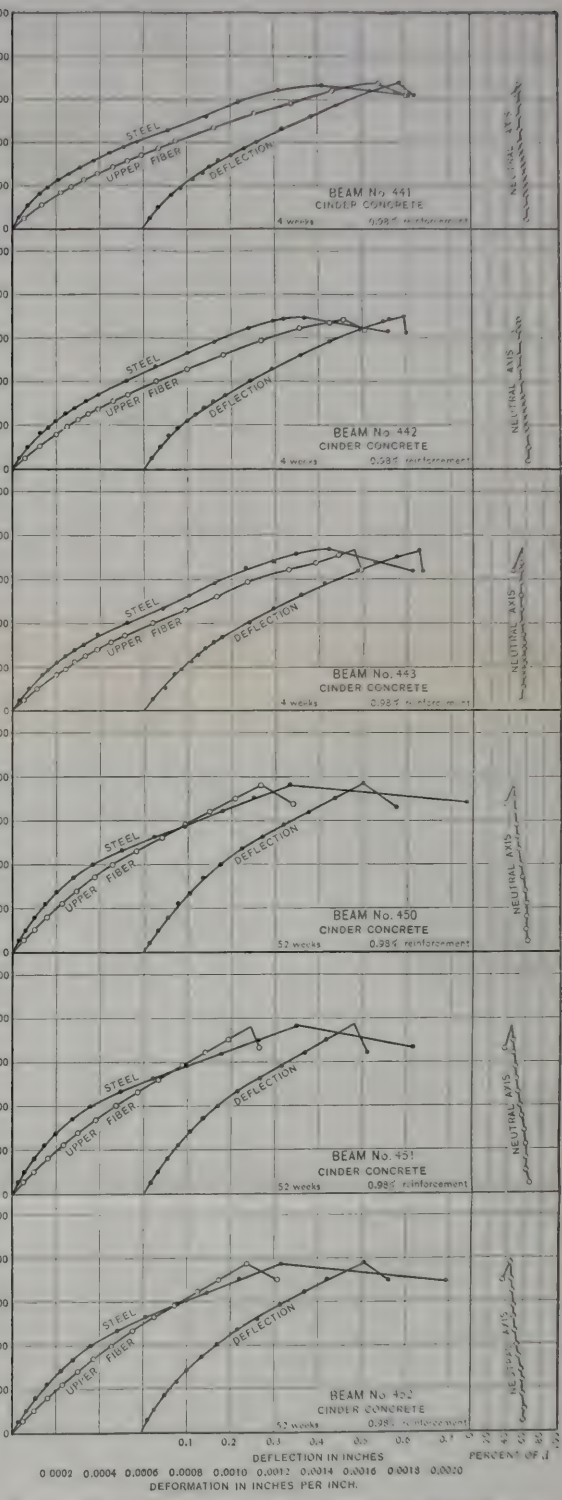

Fig. 42.—*Stress Deformation Curves of Cinder Concrete 0.98 per cent Reinforcement, Ages 4 Weeks and 52 Weeks*

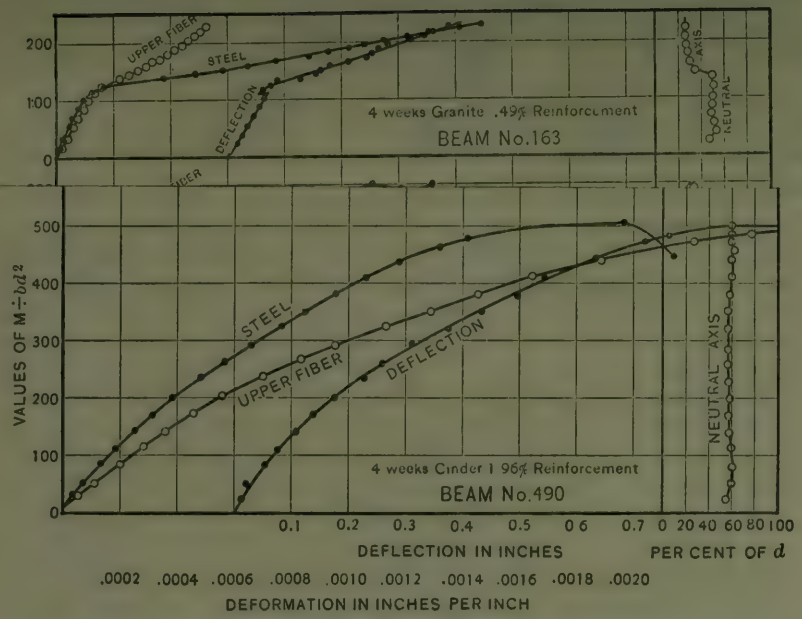

Fig. 43.—*Stress Deformation Curves of Different Aggregates at 4 Weeks with .49 and 1.96 per cent Reinforcement*

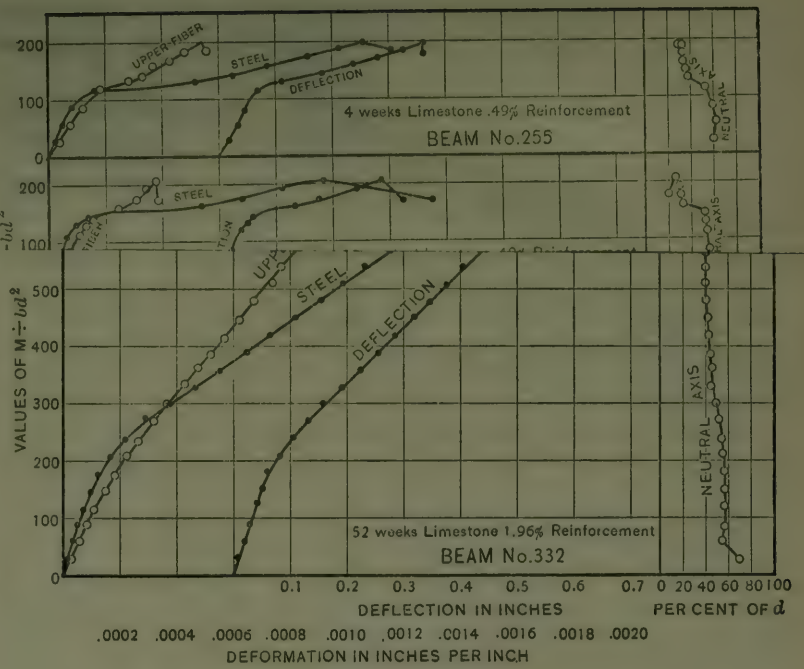

Fig. 44.—*Stress Deformation Curves of Limestone Concrete at Different Ages with .49 and 1.96 per cent Reinforcement*

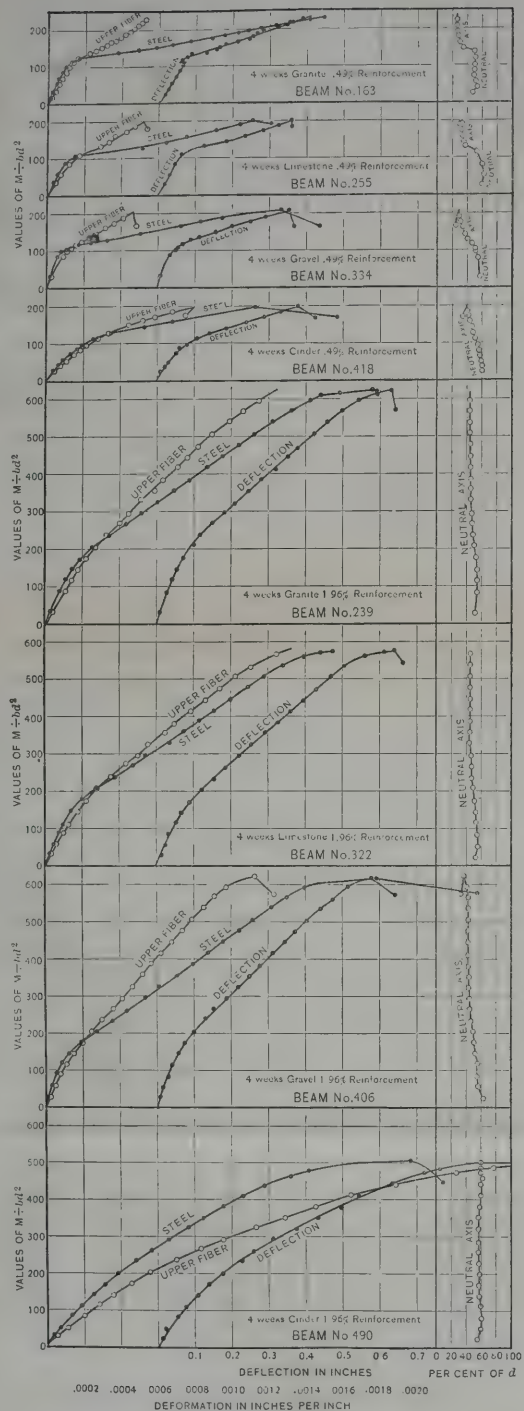

Fig. 43.—*Stress Deformation Curves of Different Aggregates at 4 Weeks with .49 and 1.96 per cent Reinforcement*

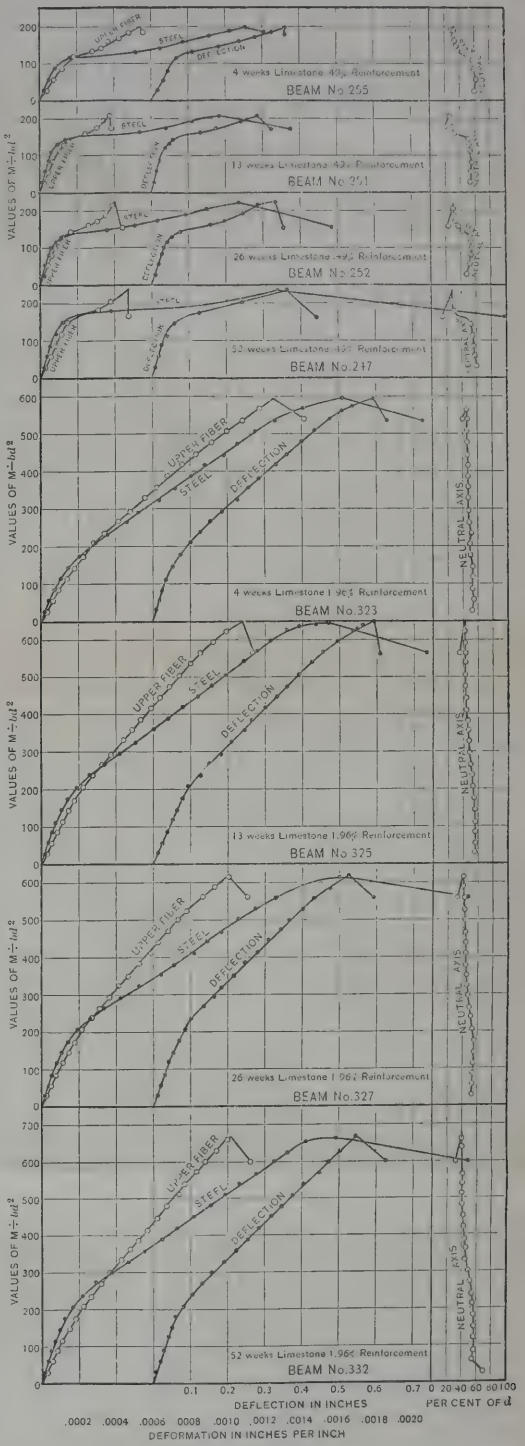

Fig. 44.—*Stress Deformation Curves of Limestone Concrete at Different Ages with .49 and 1.96 per cent Reinforcement*

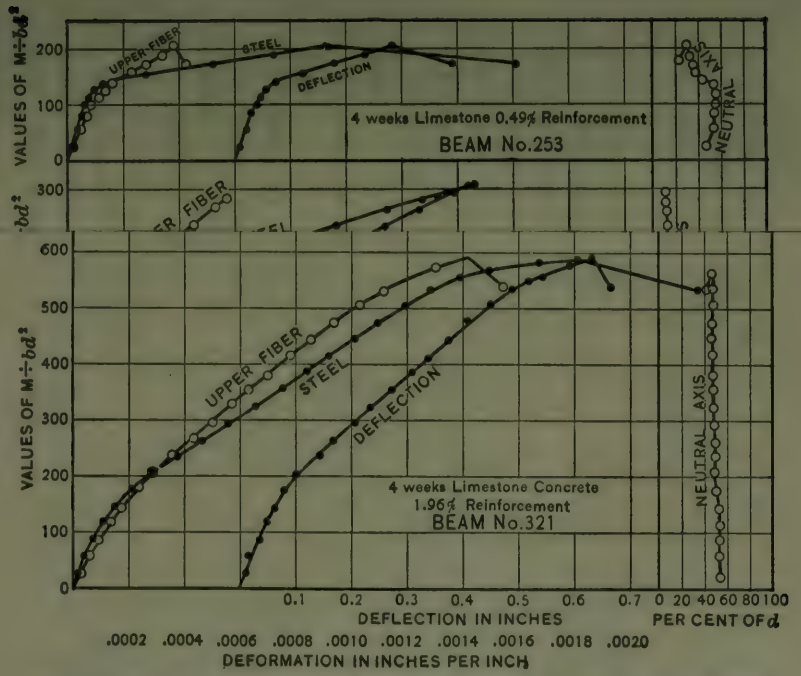

Fig. 45.—*Stress Deformation Curves of 4-Weeks Limestone Concrete with Different Percentages of Reinforcement*

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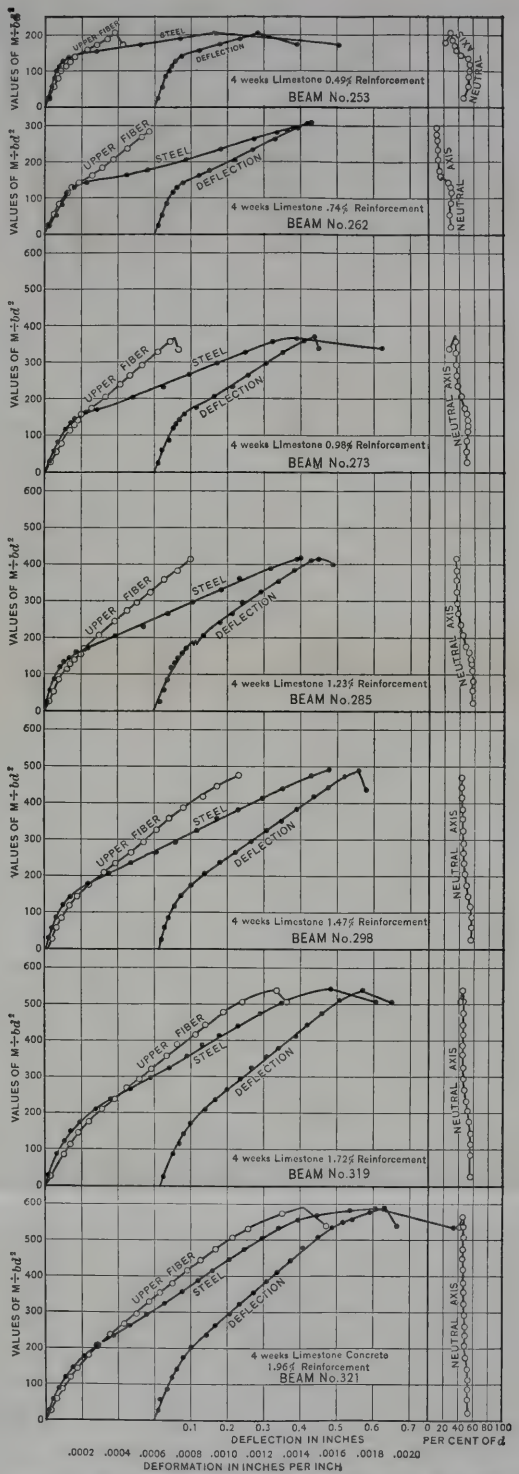

Fig. 45.—*Stress Deformation Curves of 4-Weeks Limestone Concrete with Different Percentages of Reinforcement*

and also the resisting moment, has been compared with the unit stress taken from the gross deformation curve of the cylinder for a unit deformation equal to that in the beam. The computed unit bond stress of the reinforcement in the lower fiber has also been given.

(a) EXPLANATION OF TABLES 6 TO 21

Column 1.—The register number of the beam which is the same as that of the corresponding cylinder and cube.

Column 2.—The weight of the beam within 5 pounds.

Column 3.—The weight per cubic foot of the concrete.

Column 4.—Number of one-half inch round bars used.

Column 5.—Nominal percentage of reinforcement.

Column 6.—Effective percentage of reinforcement.

Column 7.—Total area of reinforcement, in square inches, based on a diameter of one-half inch.

Column 8.—Applied load at the first crack.

Column 9.—Unit elongation of the lower fiber at first crack.

Column 10.—Maximum applied load, in pounds.

Column 11.—Deflection of the beam, in inches, at maximum load.

Column 12.—Unit elongation of reinforcement at maximum load.

Column 13.—Unit stress in reinforcement at maximum load.

Column 14.—Average yield point of reinforcement used in each beam.

Column 15.—Ratio of unit stress in reinforcement at maximum load to yield point.

Column 16.—Applied load carried by the beam at the time moments were compared. This load has been so chosen that the unit elongation of the reinforcement will be below that corresponding to the yield point of the reinforcement.

Column 17.—The unit elongation of reinforcement for the load chosen.

Column 18.—Unit stress corresponding to this load.

Column 19.—Depth of neutral axis below top of the beam.

Column 20.—The lever arm of the reinforcement. This is the distance, in inches, between the center of gravity of the compressive stresses and the tensile stresses in the lower layer of reinforce-

ment which is necessarily lower than the center of gravity of the total tensile stress in all the reinforcement.

Column 21.—The resisting moment, in inch pounds, as computed by equation (1), page 28, for the reinforcement in one layer and by equation (6), page 29, for the reinforcement in two layers.

Column 22.—External bending moment, in inch pounds, due to the applied load, the weight of the beam, and that of the deformeter.

Column 23.—Comparison of external bending moment with the resisting moment, based on the unit stress in the reinforcement.

Column 24.—Unit deformation of the upper fiber of the beam.

Column 25.—Unit compressive stress as read from the individual compressive stress gross deformation diagram of the cylinders.

Column 26.—Unit compressive stress in extreme upper fiber based on stress in reinforcement.

Column 27.—Unit compressive stress in extreme upper fiber as computed from bending moment.

Column 28.—Comparison of compressive stress, read from individual compressive stress gross deformation diagrams and compressive stress in extreme upper fiber, based on stress in reinforcement.

Column 29.—Comparison of compressive stress, read from individual compressive stress gross deformation diagrams and compressive stress in extreme upper fiber, as computed from bending moment.

Column 30.—The unit bond stress as computed from equation (3) page 28 for the applied load shown in column 16.

(*b*) DISCUSSION OF TABLES 6 TO 21

In computing the weight per cubic foot the following formula was used:

$$\text{Weight per cubic foot} = \frac{W - w}{V - v}$$

W = total weight of beam, in pounds.

w = weight of reinforcing bars, in pounds, for the beam under consideration.

V = volume of beam, in cubic feet, based on the measured breadth, depth, and length.

v = volume of reinforcing bars, in cubic feet.

The average of these columns for each particular aggregate compares very closely with the average weight per cubic foot as obtained from the weight of the cylinders and cubes.

As in the case with the cylinders and cubes, there is no increase in the weight per cubic foot with age.

The average weights per cubic foot for the beams, cylinders and the cubes for the ages of 4, 13, 26 and 52 weeks have been compiled in the following table and unless otherwise indicated is the average of 21 tests.

Table 22.—The Average Weight Per Cubic Foot of the Concrete

Age, in Weeks	Granite			Limestone		
	Beams	Cylinders	Cubes	Beams	Cylinders	Cubes
4	147.9	149.4	147.1	147.1	145.8	144.9 (18)
13	148.5	147.7	146.4	146.9	146.0 (20)	142.4
26	148.2	148.2	147.8 (20)	145.9	147.6 (20)	147.4
52	147.2	148.9	148.1	146.6	147.4	147.9
Average	148.0	148.6	147.4	146.6	146.7	145.7

Age, in Weeks	Gravel			Cinders		
	Beams	Cylinders	Cubes	Beams	Cylinders	Cubes
4	144.5	144.0	142.0 (12)	119.0	118.4	116.6 (15)
13	145.2	144.2	143.2	120.1	119.4	117.9
26	143.0	144.9	144.8 (20)	118.9	119.5	118.7
52	143.5	145.9	145.9	118.1	119.7	119.2
Average	144.1	144.8	144.0	119.0	119.3	118.1

Column 5, Tables 6–21, contains the "nominal" percentage of reinforcement. The "nominal" percentage of reinforcement is that obtained by dividing the total sectional area of the reinforcement in the beam, calling the diameter of all bars one-half inch, by the area of the cross section of the beam above the center of the lower layer of reinforcement, assuming this to be 8 by 11 inches.

Where the reinforcement is in but one layer the resistance of the beam to the flexure is proportional to this "nominal" percentage, but where the reinforcement is arranged in two or more layers this is no longer the case. For such a condition, for two equal areas of reinforcement placed at different distances below the neutral axis, that farthest away is the more effective in resisting flexure. The effect of placing the reinforcement in two layers is equivalent to reducing the percentage of reinforcement, and all comparisons between the beams of a given series must be based on this reduced or "effective" percentage and not on the "nominal" percentage which is shown in these tables. The manner of computing this "effective" percentage of reinforcement, as well as the use that is made of it, will be shown later in connection with a discussion on the effect of a variation in "effective" per cent on the behavior of a beam, page 54.

(1) **Analysis at First Crack.**—Column 8 gives the applied load at the first crack, while column 9 contains the unit elongation of the lower fiber at first crack. While a beam was being tested the surface was carefully examined with a magnifying glass in order to detect the first crack; the applied load on the beam at that time was noted and has been called the "applied load at first observed crack," and is the value reported on the log sheets, following page 128.

It should be recognized, however, that the crack was not detected until it became of such a size as to be visible to the eye through a magnifying glass. It may, however, have existed in the beam for a short time previous to this, and the load at which it occurred may be approximated as follows: Before the unit elongation of the lower fiber of the beam has exceeded the ultimate unit elongation for that particular concrete the beam acts as a homogeneous material the deformations of the upper fiber and the deflections being practically independent of the percentage of reinforcement. During this period the fiber deformations, as well as the deflections, are closely proportional to the load carried. At some load, however, which varies somewhat with the percentage of reinforcement, the unit elongation of the lower fiber exceeds the ultimate unit elongation for the concrete. The concrete below the neutral axis, beginning at the outer surface, will now fail in tension,

and will cause a portion of the weight of the beam, together with that part of the applied load which was taken care of by the tensile strength of the concrete to be thrown on the reinforcement. The increments of deformation will now no longer be proportional to the increments of load, and the curve showing the relation between the $\frac{M}{bd^2}$ and the unit elongation of the reinforcement will undergo a change of direction. The abruptness of this change depends entirely on the percentage of reinforcement, the lower the percentage the greater the change.

Since this abrupt change is due only to the cracking of the concrete in tension below the neutral axis these curves form a ready means of determining the $\frac{M}{bd^2}$ and consequently the applied load at which this cracking took place.

For some of the higher percentages that were used in this series, the change of direction took place very gradually and over a comparatively large field, so that it became rather difficult to say at what $\frac{M}{bd^2}$ the curvature started. For the lower percentages, however, no difficulty was experienced, as the curvature took place very suddenly, forming an abrupt break in the "steel curve," for which point the $\frac{M}{bd^2}$ was easily obtainable.

The applied loads corresponding to these $\frac{M}{bd^2}$ are shown in column 8, being recorded to the nearest 500 pounds applied load.

These values, however, do not correspond to the "applied load at first *observed* crack," but are in many cases considerably less. The values in column 8 are practically constant and independent of the percentage of reinforcement which is not true for the first *observed* crack. This latter value increases with the percentage of reinforcement, varying on an average from about 4000 pounds for a "nominal" percentage of reinforcement of 0.5 per cent to 7000 to 9000 pounds for one of 2 per cent.

This difference is largely due to the fact that for the greater percentages which were obtained by putting in a larger number of bars of the same diameter, a better distribution of reinforcement is

obtained than is the case with fewer bars. An inspection of the photographs of the beams showing the development of cracks will show that for the higher percentages of reinforcement the cracks are closer together, and consequently not as wide as for lower percentages. This means that the applied load that will render them visible in the case of the higher percentages will be greater than that necessary with the lower percentages of reinforcement.

The unit elongation of the lower fiber, which is given in column 8, is obtained from the unit elongation of the reinforcement corresponding to the $\frac{M}{bd^2}$, obtained as already described, by multiplying by the ratio of the distance from the neutral axis to the lower outer fiber to the distance from the neutral axis to the center of the lower layer of reinforcement.

The value for the ultimate unit elongation of the lower fiber, as obtained above, should be the same as the unit elongation at rupture of beams without reinforcement made of the same aggregate and having the same proportions and consistency as were used in the present series.

It is possible to make such a comparison with the results of the tests reported in Bulletin 344.[11] With the exception of the cinders, the material used in the series of beams without reinforcement and in that of the reinforced beams of the present Bulletin was not only from the same source but was practically identical, since it was taken from the same storage bin.

As was explained in the above bulletin it was found impossible to obtain the unit elongation of the lower fiber at the instant the beam without reinforcement broke, owing to the difficulty of reading the micrometers when the elongations were increasing so rapidly. The exact value for the ultimate-unit elongation could consequently not be obtained. The value that has been reported is that obtained from the complete set of micrometer readings taken at the last load increment preceding maximum load. This value is, therefore, less than the ultimate unit elongation by a varying amount, depending upon whether the maximum load corresponded to the load for which the last full set of readings had been

[11] U. S. Geological Survey.

taken, or was more nearly equal to this load, increased by the usual load increment for which readings were being taken in that particular test.

The values for the 13-foot beams of medium consistency have been taken from Bulletin 344 [12] and are summarized in Table 23, each value being the average of three tests.

Table 23.—Unit Elongation in Lower Fiber of Concrete Beam Without Reinforcement, as Taken from Bulletin 344 [12]

Age, in Weeks	Granite	Limestone	Gravel	Cinders
4	0.000115	0.000117	0.000095	0.000335
13	.000109	.000121	.000100	.000288
26	.000132	.000120	.000104	.000267
52	.000109	.000116	.000120	.000334
Average	.000116	.000119	.000105	.000306

For convenience of comparison it seems warranted to average the four values for each aggregate.

Table 24 contains the average of the unit elongation of the extreme lower fiber at first crack, as given in column 9, Tables 6 to 21, following page 128, for each age and aggregate. Each figure is the average of from 19 to 21 tests.

Table 24.—Unit Elongation of Lower Fiber of Reinforced Concrete Beams at First Crack

Age, in Weeks	Granite	Limestone	Gravel	Cinders
4	0.000130	0.000126	0.000103	0.000180
13	.000117	.000132	.000107	.000163
26	.000107	.000115	.000109	.000180
52	.000102	.000101	.000112	.000192
Average	.000114	.000119	.000108	.000179

In this table, also, the apparent independence of the results from the influence of age seems to warrant the averaging of the four values for each aggregate.

[12] U. S. Geological Survey.

When the method of obtaining the values that have been used in the preparation of Tables 23 and 24 are considered, the agreement between the average ultimate unit elongation of the lower fiber for each aggregate is remarkably close.

The values of the stone and gravel concrete are about the same, while that for cinders is somewhat larger, as given in Table 24, and considerably greater in Table 23. The difference between the value for the ultimate-unit elongation for the cinders of the beam series without reinforcement and that of the reinforced beam series can be satisfactorily explained. As has already been pointed out, the granite, gravel, and limestone used in the two series were almost identical, and the same 1 : 2 : 4 volume proportion was used for each. Since, however, there was not a sufficient amount of the cinder used in the first series to complete the tests to be made in the second more had to be obtained. While comparison of the physical tests for these two samples will show no considerable difference, the weight per cubic foot of that used in the plain beam series was 47, while that used in the reinforced series was 49.3, but as was pointed out in Bulletin 344,[13] the cinder concrete there used was more nearly a 1 : 2 : 5 volume proportion than a 1 : 2 : 4 mixture, and this is the probable explanation of the different values for cinder concrete in Tables 23 and 24. It is believed, however, that a study of the values of these two tables will indicate conclusively that the point at which the curve plotted between $\frac{M}{bd^2}$ and unit elongations of the reinforcement, first changes its direction corresponds closely to the occurrence of the first crack in the concrete.

(2) **Analysis at Maximum Load.**—The failure of all the beams, reported in the present Bulletin, was due to the failure of the reinforcement. The strength of the concrete did not influence the character of the failure of the beam in any way, although the load carried when the beam failed did vary slightly with the material, due to the difference in the position of the neutral axis.

Since the failure of the beam was caused by the failure of the reinforcement, a comparison of the yield point of the reinforce-

[13] U. S. Geological Survey.

ment, used in the beam, with the unit stress, based on the elongation of the reinforcement at maximum load, should be of interest.

These "maximum load" conditions have been summarized in columns 10, 11, 12, 13, 14, and 15, Tables 6 to 21, following page 128. Column 10 contains the maximum applied load in pounds.

If the fact that the yield point of the reinforcement used in the beams of this series varied from 36 000 to 43 000 pounds is taken into consideration, the results, particularly at 26 weeks, may be considered independent of the aggregate considered.

This, however, is not strictly true, particularly at the ages of 4 and 13 weeks, since the lower modulus of elasticity of the cinders will give a shorter moment arm for the same unit elongation of the reinforcement, and consequently a less load carried at the yield point of the reinforcement, than is the case for a concrete having a higher modulus of elasticity. For these ages, the aggregates can be separated into the stone and gravel concretes on one hand, and the cinder on the other. Examining the curves for the cinder beams and more particularly those for the beams containing a high percentage of reinforcement, facing page 32, it will be noticed that the curve for the upper fiber is very flat, even under the low loads at which the concrete first starts cracking. The slope of this curve with the horizontal decreases very rapidly as the load increases, the curve being almost horizontal for quite a while before the maximum load is reached. The reinforcement is affected similarly near maximum load, there being large increases in the elongation for very slight increases in the applied load.

This behavior in every case is the sign of a compression failure, the proximity to which is indicated by the degree of the slope of the upper fiber curve. In the case of the four-week cinder beams with 2 per cent "nominal" reinforcement there was probably simultaneous failure of the reinforcement in tension and the concrete in compression. The failure of these beams was not marked by a sudden increase in the readings of the lower micrometers, followed immediately by a sharp drop of the scalebeam as is the case with a typical tension failure.

For these compression failures and even, although to a less extent, for the four-week cinder beams having 1.50 and 1.75 per

cent "nominal" reinforcement, the weighing beam rose very slowly as load was being applied for some time before maximum load was reached and there was no definite indication of the failure of the reinforcement. The relation between the percentage of reinforcement and the resistance of the beam, as measured by the applied load carried, can be obtained from these tables.

When the reinforcement is arranged in one layer, as is the case for 0.5, 0.75, and 1 per cent, this comparison will lead to results that are quite near the truth. When, however, the bars are arranged in two layers the results as given in this table require considerable modification. The "nominal" percentage of reinforcement has first to be reduced to "effective" percentage and for theoretical considerations a correction applied for the varying yield point of the reinforcement, an increase in the yield point for the same sectional area of bar being equivalent to an increase in the percentage of reinforcement. Instead of making this comparison on the basis of applied loads, a better method is to reduce all values to $\frac{M}{bd^2}$: A study of the tests on this basis has been made on page 72.

The deflections, in inches, of the beams at maximum load are given in column 11.

The increase in the deflection with percentage of reinforcement is brought out in a general way by these values, but the deflection is not strictly proportional to the "nominal" percentages shown. As was the case in comparing the maximum values of $\frac{M}{bd^2}$, the deflections must also be compared on the basis of the effective percentage of reinforcement. In making this comparison, however, the method of measuring the deflection at maximum load must not be lost sight of. As has been indicated, the failure of the beam causes an abrupt and large increase in the elongation of the reinforcement. The deflection is affected similarly, though apparently to a somewhat less degree, and consequently the values reported are liable to be somewhat in error. The deflection at maximum load is, of course, the last reading immediately preceeding the sudden increase in the deflection. If this value is obtained, the deflection is correct, but if obtained a moment later it is too large

by what, in many cases, is an appreciable amount. A comparison of the deflections for maximum load will, therefore, not lead to as consistent conclusions as to the effect of an increase in the percentage of reinforcement as will a similar comparison made at some point below the maximum load for which the deflections are definitely known. A study of the influence of an increase in the amount of reinforcement on the deflection for stresses of 32 000 and 16 000 pounds per square inch in the reinforcement has been made on page 82. These tables further bring out the fact that while the load carried at the failure of the beam may differ but little for the ages of 4, 13, 26, and 52 weeks as long as the yield point of the reinforcement is the governing factor, there can nevertheless be a considerable increase in stiffness, as measured by the decreased deflections.

Column 12, Tables 6 to 21, contains the unit elongation of the reinforcement at maximum load. This was obtained by dividing the average total deformation of the reinforcement by the gauge length, 29.25 inches. With the arrangement of the deformeters that was used on the four-week tests it was not possible to read both lower micrometers of the deformeter simultaneously. The two vertical longitudinal halves of the deformeters were not insulated from each other, so that with two observers reading the lower micrometers at the same time it was impossible for either to distinguish between the click in the telephone receiver that was caused by the closing of the electric circuit through his micrometer or through that of the other observer. With this arrangement it was therefore possible to read but one lower micrometer at one time. For reasons, however, that have already been mentioned it was very important that these readings be taken simultaneously at the moment the beam fails. In order to make this possible the deformeter was altered by the introduction of a hard rubber bushing which made it possible to take simultaneous readings of the lower micrometers. In obtaining the unit elongation of the reinforcement at maximum load for the earlier tests, the following approximation was used with what are believed to be satisfactory results. Assume, first, the following data, the columns E and W

giving the total deformations of the reinforcement for each side of the beam:

Applied Load, Pounds	Total Deformation of Reinforcement	
	Deformeter E	Deformeter W
16 000	280	356
17 000	304	390
18 000	333	427
19 000	410	517
19 150 M. L.	....	533

The deformations in column E have been increasing at the rate of from 24 to 77 points for the same increment of load, while the values in column W for the same additions of load have increased by from 26 to 90 points. It has been assumed that the ratio of any increase in the total deformation in column E to the increase in column W for a given load increment is equal to the ratio of the increase in E and W for the preceding increment of load. In the data shown above the reading of the lower micrometer at maximum load was not obtained and the increase (X) of the deformation must be estimated as follows:

$$X = \frac{77}{90} \times 16 = 14$$

The lower total deformation is therefore 424, which, averaged with 533, gives the average total deformation of the reinforcement. Since, however, this is not an observed value, it was thought advisable to make a distinction in the table, so whenever the unit deformation of the reinforcement is based on an approximated average total deformation it has been inclosed in parentheses.

While the method outlined is an approximation, and introduces an error in the unit deformation of the reinforcement at maximum load, the magnitude of the error is probably small. Assume, for instance, that the error made in estimating the increment "14" for deformeter E may be either 25 per cent too large or too small, which is believed to be an extreme case. The greatest error in the average increment will then be 13 per cent while the error in the average total deformation will be less than 0.5 per cent.

The closeness of this approximation may be seen by an inspection of the deformation curves of those beams for which this method had to be used. It will be seen that the maximum load point lines up very satisfactorily with the preceding portion of the curve.

Given the unit elongation of the reinforcement and assuming a coefficient of elasticity of 30 000 000 the unit stress is easily obtained. It must be borne in mind, however, that the proportionality of stress and strain holds only within the elastic limit of the material. If, therefore, the unit elongation given in column 12 is greater than the unit elongation which corresponds to the yield point of the reinforcement, which is given in column 14 for each beam, the unit stress in the reinforcement based on this elongation will be incorrect. The computed unit stress in the reinforcement will be too great by an amount which will depend upon the difference between the observed unit elongation and the unit elongation at the yield point. While the unit stresses of column 13 have been obtained as described above, it must be remembered that the values there given are, in most cases, much too large. It is believed that the true stress in the reinforcement differs but little from the yield point, for it is a known peculiarity of reinforcement that it suffers a large increase in elongation at the yield point with but little if any increase in stress. Excepting high carbon steel, for which the yield point is not so well defined, the increase in elongation from the time the reinforcement reaches the yield point, until it again takes load, is almost without exception much greater than the whole elongation below the yield point.

That, for a tension failure, the reinforcement acts thus in a beam seems to be indicated by the fact, that after the sharp drop of the scalebeam and the sudden increase of the lower micrometer readings at maximum load, the beam will continue to deflect and the elongations of the reinforcement increase under a load several thousand pounds less than that at which the beam failed. This action will continue until the concrete begins to spall on the compression side of the beam when a more or less sudden collapse of the beam takes place.

Column 14 contains the average yield point of the reinforcement used in each beam. The values have been taken from Table 4,

p. 121, which give a summary of the physical tests of the reinforcement used in this series.

Column 15 gives the ratio of the unit stress in the reinforcement at maximum load, as computed from the measured elongation in column 12 to the yield point of the reinforcement. In no case is the unit stress in the reinforcement exactly equal to the yield point, the ratio varying from about 83 per cent for 0.5 per cent "nominal" reinforcement to about 1.30 for 2 per cent "nominal" reinforcement. In a general way, the ratio is less than 1 for percentages of reinforcement up to and including 1 per cent, and greater than 1, for all higher percentages.

Age seems to have little effect on the ratio and leads to the belief that the increase in the tensile strength of the concrete below the neutral axis, as well as the change in position of the neutral axis due to the increased stiffness of the concrete in compression, have little influence on this ratio.

Since age seems to have so little influence on this ratio the values given in column 15 have been averaged for all ages for each aggregate and are tabulated in Table 25.

Table 25.—Average Ratio of Unit Stress in Reinforcement to Yield Point at Maximum Load

Cinder		Granite		Gravel		Limestone		Grand Average	
Effective Percentage of Reinforcement	Ratio	Effective Percentage of Reinforcement	Ratio	Effective Percentage of Reinforcement	Ratio	Effective Percentage of Reinforcement	Ratio	Effective Percentage of Reinforcement	Ratio
0.49	0.86	0.49	0.83	0.49	0.82	0.49	0.79	0.49	0.83
0.74	0.93	0.74	0.89	0.74	0.95	0.74	0.89	0.74	0.92
0.98	0.99	0.98	0.97	0.98	1.04	0.98	0.93	0.98	0.97
1.08	1.13	1.11	1.08	1.12	1.12	1.11	1.05	1.11	1.09
1.24	1.24	1.30	1.06	1.30	1.20	1.30	1.17	1.28	1.17
1.48	1.35	1.54	1.13	1.54	1.22	1.53	1.10	1.52	1.20
1.62	1.38	1.71	1.17	1.72	1.29	1.71	1.28	1.69	1.28

For a ready comparison, these average values have again been averaged in Table 26. These values are shown graphically in Fig. 5, an inspection of which will show that as a general proposition it may be stated that the ratio of the unit stress in the reinforcement at maximum load to the yield point varies with the percentage of reinforcement.

(3) **Analysis of conditions in a beam at a load preceding maximum load for which the unit elongation in the reinforcement is less than that at the yield point.**—One of the most pertinent questions that can be asked in regard to any series of tests of reinforced concrete beams is that bearing on the relation of the internal resisting moment to the external bending moment. The external

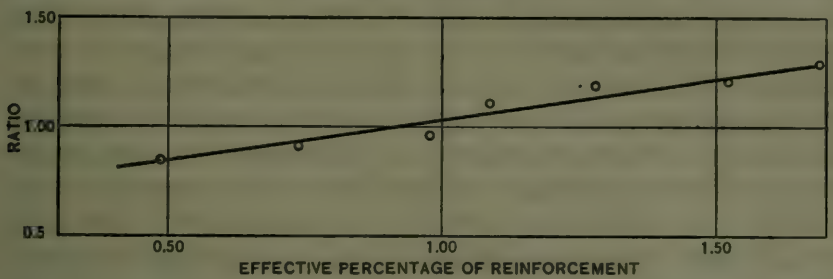

Fig. 5.—*Ratio of Unit Stress at Maximum Load to the Yield Point as a Function of the Effective Percentage of Reinforcement*

bending moment represents outside load conditions which must be met and resisted by the stresses set up in the beam. The magnitude and distribution of the load to be carried and the size of the span determine the external bending moment and are themselves determined largely by the use to which the structure is to be subjected.

The resisting moment, while depending also on the dimensions—i. e., the breadth and depth of the beam—is affected by the quality of the material used in making the beam, the care used in mixing and placing the concrete, and the age at which it is subjected to load.

If the weight of the beam and any attached test apparatus, the applied load when the beam failed, and the span are known, the

bending moment can easily be computed. The bending moment thus computed should theoretically be equal to the resisting moment of the beam.

The flexure of a simple beam develops within it two groups of horizontal stresses, one of which is above the neutral axis and is entirely compressive, while the other is below the neutral axis and is tensile. A necessary condition of equilibrium requires that the summation of the horizontal tensile stresses be equal to the horizontal compressive stresses. For a beam which contains no horizontal reinforcement above the neutral axis, all the compressive stresses that are developed are taken by the concrete alone. Below the neutral axis, the distribution of stress is, however, different. When horizontal reinforcement is used, the tensile stresses are divided between it and the concrete. As long as the unit elongation of the lower fiber is less than the unit ultimate elongation of concrete without reinforcement the division of the total tensile stress between the concrete and the reinforcement is determined by their respective coefficients of elasticity, the unit stress in the concrete at the level of the reinforcement and in the reinforcement where both have the same elongation, being directly proportional to these coefficients. When, however, the concrete cracks, these conditions begin to change; the nearer the load at a particular instant approaches the maximum load, for that beam, the greater the change. The cracks can in no case extend through to the neutral axis for below it there must always be a point at which the unit elongation is equal to the unit ultimate elongation of the concrete so that immediately above this fiber the concrete will be at the point of breaking while below it, it will just have broken. There must, therefore, be in every cross section of a beam, no matter to what extent the cracks are developed, a portion furnishing a source of tensile resistance, which would otherwise have to be provided by the reinforcement. If the concrete did not carry some tension the total tensile stresses that must be developed in a beam for equilibrium, could only be provided by an increase in the deformation of the reinforcement.

In all formulas, that are in use in the design of reinforced concrete, however, the reinforcement is assumed to carry all the

tensile stresses and this uncertain resistance of the concrete in tension is neglected.

While it is entirely warranted to neglect so uncertain an element in all formulas intended for design, it should nevertheless be included in a discussion of theoretical results. If it is not included, the effect of its neglect on any results, that may be compared with theory, should be recognized, for in many instances this is the only influence whose exclusion would account for the apparent discrepancies in some of the tabulated ratios.

A comparison of the resisting and bending moments will show, for instance, that whenever the resisting moment of the beam is based on the stress in the reinforcement, as computed from its measured deformation, it will theoretically fall below the bending moment obtained from the external loading and dimensions of the beam, since the elongation of the reinforcement, on which it is based, is smaller than what it would be if there were no tensile resistance in the concrete below the neutral axis.

Reversing this process and figuring the stress in the reinforcement from the bending moment, the values will theoretically, always be too great, for we now assume that the entire bending moment to be carried by the reinforcement, which is never the case even at maximum load.

All methods for computing the resisting moment have, heretofore, been based on the tensile stress in the reinforcement. Neglecting the effect of the tensile stress of the concrete in adding to the resisting moment of the reinforcement, the quantities involved, when this method is used, are the unit stress in the reinforcement, the percentage of reinforcement, the position of the neutral axis and the character of the stress deformation diagram of concrete in compression, as affecting the position of the center of gravity of the compressive stresses. Theoretical discussions indicate however, that the various assumptions as to the character of this curve have very little effect on the position of the center of the compressive stresses, although it does affect the extreme fiber stress of the concrete in compression.

In the discussion of all tests that have been made up to the present time, the resisting moment has been thus based on the

measured stress in the reinforcement, and while it does not lead to results that are strictly comparable to the bending moment it has nevertheless the sanction of wide usage. A further reason for the use of this method has been the supposedly greater reliability of data which is based on the properties of steel. As steel is manufactured in a mill with what is believed to be greater care than is exercised in the mixing and molding of concrete, the belief that it is more homogeneous and reliable is perhaps not altogether unfounded.

For stresses below the yield point, steel has, further, a constant coefficient of elasticity, which is unaffected by variations in either the yield point or the ultimate strength. For a given elongation in the steel, the unit stress is, therefore, easily obtained for all elongations below that corresponding to the yield point. When the failure of a beam is due to the failure of the reinforcement, the unit stress in the reinforcement is usually very little above the yield point, while for those cases in which the failure of the beam is by compression, diagonal tension or bond—i. e., a failure caused by some weakness of the concrete—the unit stress in the reinforcement at maximum load is always well below the yield point.

In no case, however, not even for the beams failing by tension, is the ultimate strength of the reinforcement approached, so that as far as the initial failure of the beam is concerned the ultimate strength is unimportant.

While the above method of computing the resisting moment makes use of the greater portion of the tensile stresses below the neutral axis, another method, based on the compressive stresses above the neutral axis should, theoretically, lead to better results, since the action of no stresses is neglected.

That concrete under compression in a beam acts in an identical manner with concrete in pure compression is the fundamental assumption on which this method is based. While this assumption may be a debatable question a majority hold that, at the moment of failure in compression, the only portion of the concrete, that is seriously affected, is the extreme outer fiber; for, considering the fibers above the neutral axis, each is adjacent to one which is stressed higher and to another which is stressed lower than itself.

The latter helps to aid or reinforce the fiber in question, while the former will itself be aided by it. If, however, we consider, as is nearly always done, all the horizontal compressive forces applied at a point one-third of the distance to the neutral axis below the top of the beam, we would have conditions which would approximate those in a horizontal strut loaded at the upper limit of the middle third. In this case, we would have zero stress in the extreme lower fiber of this imaginary strut, and this would correspond to the zero stress at the neutral axis of the beam. It would seem that the two cases are almost parallel, particularly over the middle third of the beam where the shear is practically zero. While the ultimate micrometer reading on either side of one of the regular cylindrical compression pieces is in no case zero, it frequently happens that the ultimate deformation of one side is as much as twice that of the other. This would indicate that the load is eccentrically applied to the cylinder and while it never gets out to the limit of the middle third, the conditions nevertheless approximate those assumed above for a beam. The results arrived at by the use of this method would further appear to warrant the correctness of the assumption that the concrete in compression in a beam acts similarily to that in a simple compression test.

The physical properties of concrete, while paralleling, in a general way, those of steel, are much more sensitive to external influences. From a discussion of the compression tests on pages 98 to 109 it may be concluded, in a very general way, that concrete in compression has a yield point, which is fairly well defined, and below which the relation between unit stress and unit strain can be represented by a straight line whose slope is the initial coefficient of elasticity. The unit stress for any deformation below this yield point can, therefore, readily be obtained when the coefficient of elasticity is known.

This coefficient of elasticity, unlike that for steel, which is fairly constant, is subject to considerable variation. It varies with material and proportions; it increases somewhat with age, and decreases as the concrete is made of wetter consistency. While the increase with age is slight and could be neglected, the variation due to material, proportions, and consistency must be considered.

Unfortunately, this is not all that must be taken into account, for in all beams that fail by the compression of the concrete, and in many that fail by the tension of the reinforcement, the unit stress in the concrete is above the yield point. The unit stress can not, therefore, be obtained directly from the elongation and the initial coefficient of elasticity, as was the case for unit stresses below the yield point. A study of the compression tests shows, however, that the stress gross deformation curves for the individual cylinders differ in but few instances more than is permissible from the average curve of a group, so that we may assume that any material used in concrete of a given proportion, age, and consistency is sufficiently homogeneous to yield practically identical results on similar test pieces. With the aid of this curve, the unit stress for any given deformation is easily obtainable, whether it be above or below the yield point of the concrete.

Since this is the case, we are furnished with a method of computing the resisting moment of the beam which does not, as does the method based on the unit stress in the reinforcement, neglect a portion of the horizontal stresses in the beam. It does, however, introduce a source of error, in necessitating an assumption as to the character of the stress deformation diagram above the neutral axis. Yet, even with the assumption that has been made in this bulletin, and which has been maintained constant for all degrees of loading and all aggregates, the results obtained by this method are more nearly comparable with the external load conditions than are those which are based on the reinforcement, and which neglect the tensile stresses in the concrete.

Theoretically, this method would be applied in the following manner: The average stress gross deformation diagram of the concrete under consideration would be entered, with the unit deformation of the extreme upper fiber of the reinforced beam at the $\frac{M}{bd^2}$ for which the resisting and the bending moment were to be compared. With this unit compressive stress column 25, tables 6 to 21 as a basis, the total compressive stress would be computed, making use of the particular stress deformation diagram above the neutral axis which has been assumed in this bulletin. The resisting moment would then follow, by multiplying by the

distance from the center of gravity of the compressive stresses to that of the tensile stresses in the reinforcement.

The ratio of the resisting moment thus computed, to the bending moment could then be obtained. Since, however, we already have in column 26 the unit compressive stress in the extreme upper fiber, based on the tensile stress in the reinforcement, and in column 25 the unit compressive stress, taken from the compressive stress gross deformation diagram for the compressive cylinder, paralleling the beam under consideration it has been thought advisable to reverse the process outlined above, and compute the extreme fiber stress from the bending moment. This has been done and the values entered in column 27.

Making use of the necessary condition of equilibrium, that the sum of all the horizontal forces must be equal to zero, it is possible to figure the unit compressive stress of the extreme upper fiber of the beam from the tensile stress below the neutral axis. If, as a basis for this computation, the total tensile stress—i. e., the total tensile stress in the reinforcement plus the total tensile stress in the concrete—is used, the value obtained for the unit compressive stress in the extreme upper fiber of the beam should be the same as that which would be obtained if it had been computed directly from the bending moment.

If, however, as was done for the values in column 26, it is based on the total tensile stress in the reinforcement alone, the values obtained for the unit compressive stress will be smaller than that obtained from the bending moment, due to the neglect of the tensile stresses in the concrete below the neutral axis.

The values given in column 26 will, therefore, be found to be smaller than if computed from the bending moment, making use of the known position of the neutral axis.

Column 26 contains the unit compressive stress in the upper fiber of the beam as it would be computed from the bending moment, using the position of the neutral axis as given in column 18, the compressive stress deformation diagram with $q = \frac{1}{2}$, as has been assumed throughout this bulletin, and the external bending moment as given in column 22. Theoretically the values in column 27 would be obtained in this manner, but since, in column 26, we already have the unit compressive stress in the upper fiber,

based on the total tensile stress in the reinforcement, and in column 22 the ratio of the resisting moment, based on the tensile stresses in the reinforcement, to the bending moment it was only necessary to divide the values in column 26 by those in column 23.

Examining the values of $\frac{M_r}{M_b}$ given in column 23, we find, as might have been expected, that the ratio more nearly approaches unity as the percentage of reinforcement increases, due to the relatively greater importance of the neglect of the tensile resistance of the concrete below the neutral axis for the lower percentages.

As might be expected, the same behavior is indicated by the ratio in column 28, which is more nearly equal to unity, the higher the percentage of reinforcement.

The values of the ratio of the unit compressive stress in the upper fiber, as figured from the bending moment to the unit compressive stress, taken from the cylinders, is given in column 29 and is, as it should be, more nearly independent of the percentage of reinforcement than are the values in column 28, although the ratio does increase somewhat with the percentage of reinforcement.

The value of the computed unit bond stress, column 30, is seen to be entirely independent of the percentage of reinforcement, and has therefore been averaged for each age and aggregate. Under the heading of "Remarks" is given the unit bond stress at maximum load for tests on bond test pieces, the details of which have been given on page 17, and also the ratio of this unit bond stress to the average computed unit bond stress in the reinforced beams given in column 30. An examination of this ratio will show that in no case was the beam in danger of failure due to the slipping of the bars since the value of the ratio was in no case less than 3.

(c) THE EFFECT OF VARIATIONS IN THE PERCENTAGE OF REINFORCEMENT ON THE BEHAVIOR OF THE BEAM

The influence of treatment and environment is of great importance in the case of concrete. Concrete is in a state of change for a long time after it has been placed, a continual though slow increase in strength being accompanied by a corresponding increase in stiffness. For a given age, aggregate, and consistency its

strength varies almost directly as the percentage of cement, while a change in consistency causes a marked change in the ultimate strength for periods even up to one year. The strength of the concrete is greatly affected by the kind of aggregate used, and when this is kept constant, it is again affected by the uniformity of the grading, and, for the same grading, whether it grades down from a large or a comparatively small size. Even for a good hard stone, the fact that it was crushed and screened dry or wet exerts a marked influence on the strength and stiffness, while the character and amount of sand used in the concrete introduces another variable whose importance must not be overlooked.

When, therefore, concrete is combined with steel in a reinforced beam the behavior of the beam under load depends largely on the quality of the concrete used. The behavior of the beam, particularly one in which the percentage of reinforcement is comparatively high, is also slightly influenced by a peculiarity, which is common to all qualities of concrete, though in a different degree, in the following manner:

As was seen by an inspection of the diagrams giving the average compressive stress gross deformation curves for the concrete used in the present series, the maximum unit stress within which the relation of stress to deformation can be accurately represented by a straight line varies from 30 to 40 per cent of the ultimate strength. Even at a unit stress 50 per cent in excess of this amount, the variation from a straight line is but between 4 and 5 per cent. That is, the unit stress as given for a certain deformation on the curve is 4 or 5 per cent less than that computed from the given deformation using the initial coefficient of elasticity.

If, in a given series of beams in which the concrete is identical, we arbitrarily fix certain intensities of stress in the lower layer of the reinforcement, the behavior of the beam will, for all intensities of unit compressive stress in the extreme upper fiber which are greater than that corresponding to the limit of the straight-line variation, be governed largely by the character of the compressive stress gross deformation diagram. For this case, therefore, the behavior of the beam will not be in a direct relation to the percentage of reinforcement. For all unit compressive stresses in the extreme upper fiber which are below this value the behavior

of the beam will be a direct function of the percentage of reinforcement.

With these peculiarities in mind a study has been made of the relation between the percentage of reinforcement and the strength and the stiffness of the reinforced beams.

Nearly all building laws and specifications prescribe an allowable working stress of 16 000 pounds per square inch in the reinforcement. It is a matter of interest, therefore, to know exactly (1) how an actual beam for which this stress has been developed in the reinforcement would behave under load; (2) the load carried, and its variation with the amount of reinforcement; (3) the position of the neutral axis; (4) the effect of an increase or decrease of the area of the reinforcement; (5) the relation of the unit compressive stress in the extreme upper fiber to the unit tensile stress in reinforcement.

The questions are often asked (1) to what extent have the cracks developed below the neutral axis when the beam is subject to working loads; (2) does the deflection vary with the percentage of reinforcement; (3) does the allowable deflection increase directly with the span for a given concrete and percentage of effective reinforcement; (4) what is the effect of variations in the unit stress of the reinforcement; (5) what is the effect of an extreme variation in the yield point of the reinforcement.

While undoubtedly other studies leading to interesting results can be made from the data herein presented, it is thought that some of the principal points of interest in reinforced concrete have been covered and are summarized as follows.

Principal Considerations in Design of Reinforced Concrete Beams

With a view to furnishing information on these points, the following studies (for a maximum load and a unit stress of 16 000 and 32 000 pounds per square inch in the lower layer of reinforcement) have been made, involving the influence of the character of the aggregate and age of the concrete in the relation of the effective percentage of the reinforcement to:—(1) the position of neutral axis, (2) value of $\frac{M}{bd^2}$, (3) compressive stress in extreme upper fiber, (4) deflection.

As has already been indicated, it is necessary to use from two to eight, one-half inch round bars in order to bring about the desired variation in the nominal percentage of reinforcement. As the test beams were only 8 inches wide, it would probably not have been possible to place more than four bars in one layer and prevent the splitting of the concrete in the plane of the reinforcement. When, therefore, more than four bars were used they had to be arranged in two layers as shown in Fig. 1.

For those cases in which the reinforcement consisted of two, three, or four bars the entire area of reinforcement was effective in the same degree in resisting flexure. When, however, more than four bars were used, and it became necessary to place the reinforcement in two layers, this was no longer true. A square inch of reinforcement in the lower layer becomes now more effective than a square inch in the upper layer, in resisting flexure, in proportion to the distance from the neutral axis to the center of the lower layer of reinforcement and from the neutral axis to the upper layer of reinforcement.

If, therefore, the area of the reinforcement in the upper layer were multiplied by the ratio between the distance from the neutral axis to the upper layer and the distance from the neutral axis to the lower layer, an area would be obtained which, when added to the area of the reinforcement in the lower layer, would give a new area of reinforcement concentrated in the lower layer and causing the beam to duplicate its behavior for the original arrangement of the reinforcement in two layers.

While it was thought unnecessary to give in detail all the computations required in the preparation of Figs. 6 to 21, it was thought best to include the computation sheet for one set of beams in order that the basis underlying Figs. 6 to 21 might be clearly understood.

Table 26, p. 60, shows, therefore, the computation sheet for beams of 1 : 2 : 4 granite concrete tested at the age of 13 weeks.

Column 1 contains the register number of the beam, while column 2 contains the number of one-half-inch round bars with which each beam was reinforced.

Column 3 contains the maximum value of $\frac{M}{bd^2}$. For those

beams for which the maximum load was observed, this value could be figured directly from the maximum applied load, the weight of the deformater, and that of the beam. In computing bd^2 the nominal dimensions, 8 inches wide, 10 inches to the center of the lower layer of reinforcement were adhered to. Whenever the tabulated values have been followed by an asterisk, they are based on actual measured values.

The unit deformation of the upper fiber at maximum load is given in column 4. In but a few instances was this quantity measured directly. Since the failure of all the beams was due to the tension in the reinforcement the readings of the lower micrometers at maximum load were far more important than those at the top of the beam. The observer on each side of the beam therefore concentrated his attention on the lower micrometer when maximum load was being approached, in order to detect the first sign of failure in the reinforcement. In order, therefore, to approximate the unit deformation of the upper fiber at maximum load it was necessary to produce the upper fiber curve (Figs. 41 to 45, facing p. 32) beyond the $\frac{M}{bd^2}$ corresponding to the last load increment preceding maximum load until it intersected a horizontal line through the maximum value of $\frac{M}{bd^2}$. The values thus obtained were entered in column 4.

In a few instances the beam failed just after a full set of readings had been taken, and before any additional load had been applied. The values thus obtained by direct measurement have been followed by an asterisk in column 4.

In column 5 is given the unit deformation of the reinforcement. These values were obtained, as already indicated, from the reading of the lower micrometer just previous to the sudden increase in the readings which indicated that the yield point of the reinforcement had been reached. Since this reading was considered one of the most important in the entire test it was always observed and therefore all the values in the column have been followed by an asterisk.

The percentage depth of the neutral axis below the top of the beam is given in column 6, and is based on the usual assumption

that the deformations are proportional to the distance from the neutral axis. Since these values have been obtained from those in columns 4 and 5, they involve in many cases an approximate value, particularly of the unit deformation of the upper fiber.

Column 7 contains the average yield point of the reinforcement used in each beam and are the averages of the individual values given in the summary of the tests on the reinforcement. (Table 4.) The usual percentage of reinforcement is obtained by dividing the total sectional area of the reinforcement by the cross section of the beam above the center of the lower layer of reinforcement.

The values in column 8 have been obtained in this way, and are based on bars of one-half inch nominal diameter, a constant breadth of 8 inches and a constant depth to the center of the lower layer of reinforcement of 10 inches. In all discussions that follow, this percentage of reinforcement will be referred to as the "nominal" percentage.

In order to obtain the "effective" percentage at maximum load, which is the percentage of reinforcement which, when concentrated in the plane of the lower layer of reinforcement, will cause identical behavior under load, it is necessary to multiply the area of the reinforcement in the upper layer by the ratio between the distance from the neutral axis to the upper layer of the reinforcement and the distance from the neutral axis to the lower layer of reinforcement. This reduced area is added to the cross section of the lower layer, and the sum divided by the cross section of the beam above the lower layer. Since the final study was to be made on average values, this reduction was made only for the average values of the position of the neutral axis as given in column 6.

The values thus obtained for the "effective" percentage, theoretically, still require modification at maximum load, due to the fact that the average yield point of the reinforcement used in the different beams is not the same. An increase in yield point is equivalent to an increase in the percentage of reinforcement, and in order to reduce all sets of beams to the same basis, the "effective" percentages of column 9 have been altered to correspond to

a yield point of 40 000 pounds per square inch, the approximate average yield point of all the reinforcement used, and are given in column 10.

The value of the deflection, in inches, at maximum load is shown in column 11. With the exception of the values in columns No. 1, 2, and 8 all values, that have been mentioned up to this point, refer to maximum load conditions only.

The next five columns give conditions in the beam at a unit stress of 32 000 pounds per square inch in the lower layer of the reinforcement. Assuming a modulus of elasticity of 30 000 000, the unit deformation corresponding to a stress of 32 000 pounds per square inch is 0.001067. With this as a basis, the values in columns 12 to 16, inclusive, were obtained as follows: Figs. 41 to 45, facing page 32, for the above unit deformation for the lower fiber the corresponding $\frac{M}{bd^2}$ was read from the steel curve and entered in column No. 12.

With the value of $\frac{M}{bd^2}$ corresponding to a unit deformation in the reinforcement of 0.001067 known, the unit deformation of the upper fiber was read from the upper curve and entered in column 13.

The percentage depth of the neutral axis below the top (column 14) and the deflection, in inches, at the center of the beam (column 15) were obtained in the same manner.

The "effective" percentage in column 16, and also the values in column 9, were obtained from the known distribution of the reinforcement in the beam and the known position of the neutral axis.

Columns 17 to 21, inclusive, contain the same information for a unit stress of 16 000 pounds per square inch in the lower layer of the reinforcement as is given in columns 12 to 16 for a unit stress of 32 000 pounds per square inch.

An inspection of columns 16 and 21 will indicate that the higher the unit stress in the lower layer of reinforcement the higher the neutral axis, and therefore the greater the "effective" percentage of reinforcement.

1	2	3	
Beam No.	Number of ½-Inch Round Rods	Maximum Value of $\frac{M}{bd^2}$	
165	2	1 229.47	0
166	2	1 220.26	
167	2	1 223.68	
Average		224.47	
177	3	1 301.77	
178	3	1 325.47	
179	3	1 320.67	
Average		315.97	
189	4	1 407.29	
190	4	1 402.06	
191	4	1 378.87	
Average		396.07	
201	5	1 433.68	
202	5	1 435.18	
203	5	1 451.08	
Average		439.98	
213	6	1 522.59	
214	6	1 529.68	
215	6	1 521.29	
Average		524.52	
225	7	1 573.38	
226	7	1 584.69	
227	7	1 589.69	
Average		582.59	
243	8	1 665.29	
244	8	1 665.11	
245	8	1 690.10	
Average		673.50	

Table 26.—Computation Sheet for Beams of 1 : 2 : 4 Granite Concrete Tested at 13 Weeks

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
											Conditions in the Beam at a Unit Stress of 32 000 lbs. per sq. in. in the Lower Layer of Steel					Conditions in the Beam at a Unit Stress of 16 000 lbs. per sq. in. in the Lower Layer of Steel				
Beam No.	Number of ¾-Inch Round Rods	Maximum Value of M / bd²	Unit Deformation Upper Fiber at Maximum Load	Unit Deformation of Reinforcement	Percentage Depth of Neutral Axis Below Top Beam	Average Yield Point of Reinforcement Used	Nominal Percentage of Reinforcement	Percentage of Effective Reinforcement	Uniform Percentage of Reinforcement	Deflection in Inches at Maximum Load	M / bd²	Unit Deformation Upper Fiber	Percentage Depth Neutral Axis Below Top	Deflection in Inches	Effective Percentage Reinforcement	M / bd²	Unit Deformation Upper Fiber	Percentage Depth Neutral Axis Below Top	Deflection in Inches	Effective Percentage Reinforcement
165	2	[1] 229.47	0.000480	[1] 0.001138	29.5	42 230	.....	.....	.....	[1] 0.350	223.5	0.000460	30.5	0.323	.....	180.0	0.000322	37.5	0.170	.....
166	2	[1] 220.26	[1] 418	[1] 1176	[1] 26.2	42 200	.....	.....	.....	[1].325	209.0	393	27.0	.296	.....	165.5	276	34.8	.156	.....
167	2	[1] 223.68	464	[1] 1164	28.3	41 910	.....	.....	.....	[1].345	210.0	428	28.8	.292	.....	165.0	280	35.1	.138	.....
Average	.....	224.47	.000454	.001159	28.0	42 110	0.49	0.49	0.517	.340	214.2	.000427	28.8	.304	0.491	170.2	.000293	35.8	.155	0.491
177	3	[1] 301.77	.000544	[1].001215	31.2	41 940	.....	.....	.....	[1].410	[1] 280.5	.000490	[1] 31.5	[1] .340	.....	197.0	.000305	36.9	.158	.....
178	[illegible]	[1] 325.47	[1] 560	[1] 1248	[1] 31.0	43 390	.....	.....	.....	[1].410	298.5	503	32.1	.353	.....	210.0	326	38.1	.172	.....
179	3	[1] 320.67	564	[1] 1070	33.0	43 470	.....	.....	.....	[1].390	[1] 320.7	564	34.0	[1] .390	.....	226.5	•333	39.0	.182	.....
Average	.....	315.97	.000556	.001178	31.7	42 930	.74	.74	.790	.403	299.9	.000519	32.5	.361	.736	211.2	.000321	38.0	.171	.736
189	4	[1] 407.29	.000695	[1].001226	36.2	41 950	.....	.....	.....	[1].455	372.0	.000626	37.0	.379	.....	251.0	.000371	41.3	.203	.....
190	4	[1] 402.06	690	[1] 1374	33.6	42 480	.....	.....	.....	[1].475	343.0	568	34.7	.351	.....	245.0	375	41.6	.187	.....
191	4	[1] 378.87	634	[1] 1176	36.7	40 670	.....	.....	.....	[1].400	363.0	[illegible]	36.4	.365	.....	254.5	[illegible]	42.6	.186	.....
Average	.....	396.07	.000673	.001259	35.5	41 700	.98	.98	1.024	.443	359.3	.000599	36.0	.365	.982	250.2	.000378	41.8	.192	.982
201	5	[1] 433.68	.000689	[1].001443	36.0	40 920	.....	.....	.....	[1].430	390.0	.000508	36.3	.333	.....	262.0	.000368	41.0	.172	.....
202	5	[1] 435.18	713	[1] 1323	35.2	41 460	.....	.....	.....	[1].435	380.5	596	35.9	.344	.....	258.0	361	40.7	.176	.....
203	5	[1] 451.08	725	[1] 1479	35.0	40 410	.....	.....	.....	[1].465	390.0	589	35.6	.352	.....	[1] 265.7	[1] 363	[1] 40.5	.185	.....
Average	.....	439.98	.000709	.001415	35.4	40 930	1.23	1.11	1.139	.443	386.8	.000598	35.9	.343	1.112	261.9	.000364	40.7	.178	1.103
213	6	[1] 522.59	.000819	[1].001321	37.8	41 460	.....	.....	.....	[1].470	[1] 446.1	.000670	38.7	.365	.....	290.0	.000405	43.4	.179	.....
214	6	[1] 529.68	845	[1] 1494	37.7	41 230	.....	.....	.....	[1].525	437.0	667	38.4	.381	.....	290.0	410	43.5	.203	.....
215	6	[1] 521.29	837	[1] 1422	36.8	41 080	.....	.....	.....	[1].495	422.0	631	37.2	.355	.....	276.0	376	41.6	.173	.....
Average	.....	524.52	.000834	.001412	37.4	41 260	1.47	1.30	1.337	.497	435.0	.000656	38.1	.367	1.294	285.3	.000397	42.8	.185	1.279
225	7	[1] 573.38	.000933	[1].001503	40.3	41 180	.....	.....	.....	[1].510	479.5	.000741	40.9	.379	.....	312.0	.000444	45.0	.192	.....
226	7	[1] 584.69	855	[1] 1694	38.3	42 110	.....	.....	.....	[1].505	490.0	691	39.3	.360	.....	314.0	403	43.2	.174	.....
227	7	[1] 589.69	890	[1] 1443	39.1	40 750	.....	.....	.....	[1].495	494.0	723	40.4	.362	.....	320.5	428	44.7	.185	.....
Average	.....	582.59	.000826	.001547	39.2	41 350	1.72	1.54	1.588	.503	487.8	.000718	40.2	.367	1.533	315.5	.000425	44.3	.184	1.520
243	8	[1] 665.29	.001115	[1].001706	40.0	41 790	.....	.....	.....	[1].615	546.0	.000822	43.6	.414	.....	346.5	.000487	47.9	.217	.....
244	8	[1] 665.11	950	[1] 1405	40.1	41 780	.....	.....	.....	[1].530	556.0	734	40.8	.386	.....	[1] 356.7	[1] 427	[1] 44.5	[1] .195	.....
245	8	[1] 690.10	1062	[1] 1831	38.3	41 400	.....	.....	.....	[1].595	548.0	725	40.5	.382	.....	343.0	414	44.0	.189	.....
Average	.....	673.50	.001042	.001647	39.5	41 660	1.96	1.72	1.791	.580	550.0	.000760	41.6	.394	1.712	348.7	.000443	45.5	.200	1.694

[1] Actual measured values, or computed from actual measured values.

While Table 26 has been given as an illustration of the basis of the tabulated values, and as furnishing in detail the method of calculation that was used, like all tabulated values they are unsatisfactory for the purpose of comparing a large number of results. Therefore but one set of computations has been published and the remainder of the data presented graphically in Figs. 6 to 21, pages 62 to 95, which will now be discussed.

(1) **Variation in the Position of the Neutral Axis with the "Effective" Percentage of Reinforcement.**—An accurate knowledge of the position of the neutral axis is one of the first requisites in determining the resistance of a beam to flexure. It seems logical, therefore, to discuss the change in the position of the neutral axis when the amount or disposition of the reinforcement is altered, before taking up the resistance of the beam to flexure.

Figs. 6 to 9, pages 62 to 65, have therefore been prepared to show the change in the position of the neutral axis with change in percentage of reinforcement. Each point in the figures is the average of three tests and every figure gives the results of the tests on a given aggregate made at a particular age. On each figure three curves have been drawn. One shows the relation between the variables under consideration for a unit stress in the lower layer of steel equal to 16 000 pounds per square inch, one for a unit stress of 32 000 pounds, and one has been drawn for maximum load conditions.

A general inspection of these curves will show that if we except the points observed for limestone concrete beams which were reinforced with two, one-half inch round bars or 0.5 per cent reinforcement, the curves are all very uniform, and all sets seem to have the same general shape irrespective of the aggregate considered.

What difference there is in the uniformity seems to be in favor of the 16 000 pounds stress curve, while that for maximum load conditions is the most irregular of the three.

The curve for maximum load conditions is perhaps even more regular than might be expected when the various reductions that have been made in the preparation of these figures is taken into consideration.

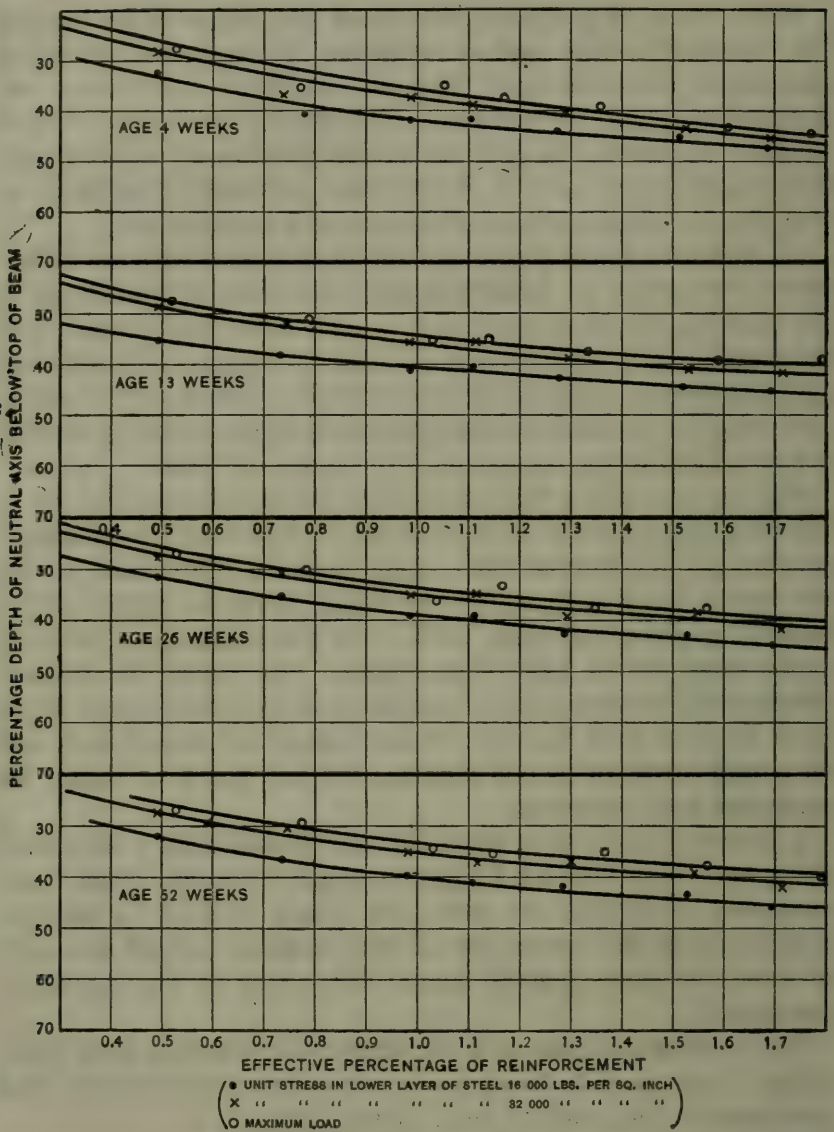

Fig. 6.—*Relation Between Position of Neutral Axis and Effective Percentage of Reinforcement for Granite Concrete*

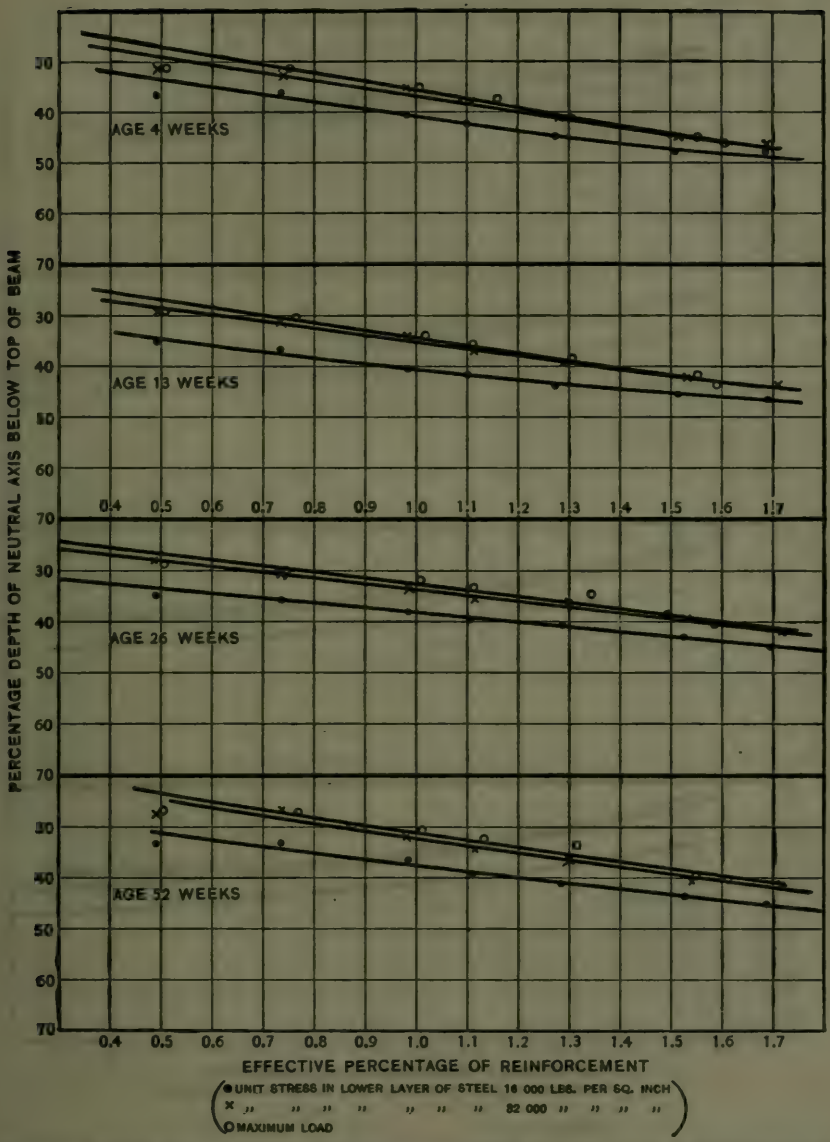
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
PERCENTAGE DEPTH OF NEUTRAL AXIS BELOW TOP OF BEAM
EFFECTIVE PERCENTAGE OF REINFORCEMENT
● UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× „ „ „ „ „ „ „ 32 000 „ „ „ „
○ MAXIMUM LOAD

Fig. 7.—*Relation Between Position of Neutral Axis and Effective Percentage of Reinforcement for Limestone Concrete*

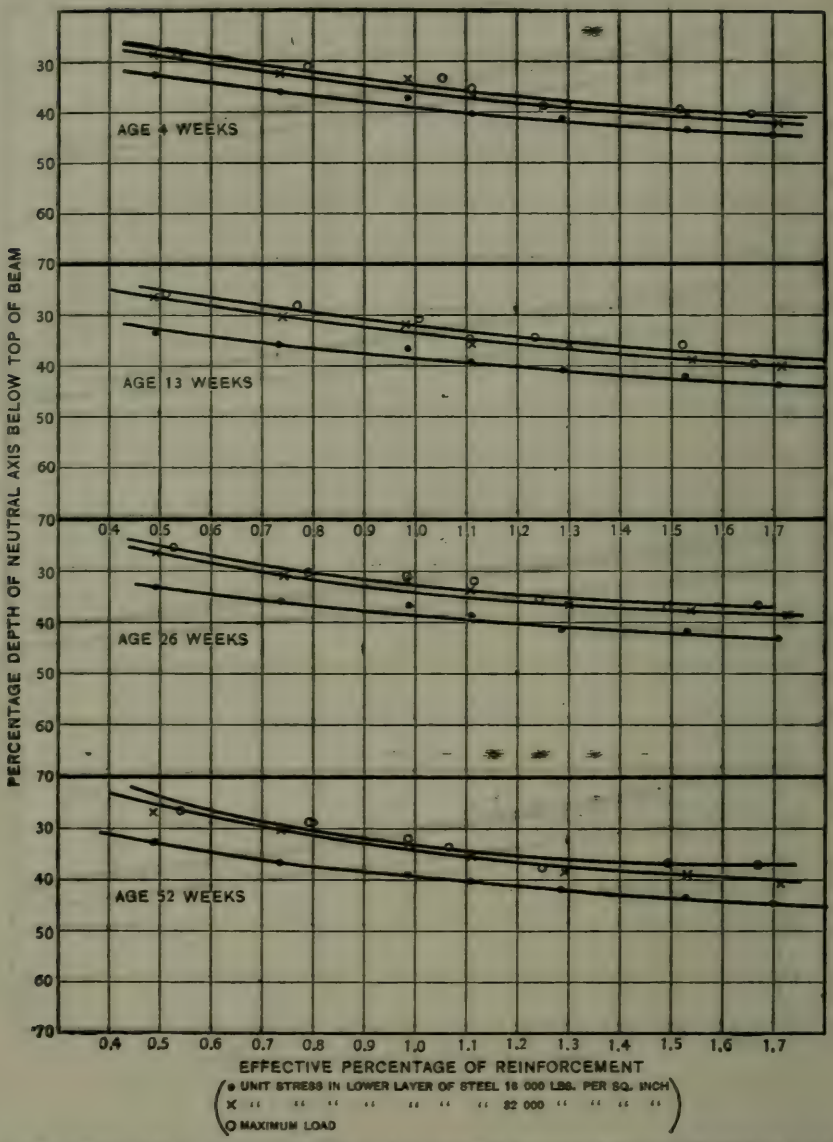

Fig. 8.—*Relation Between Position of Neutral Axis and Effective Percentage of Reinforcement for Gravel Concrete*

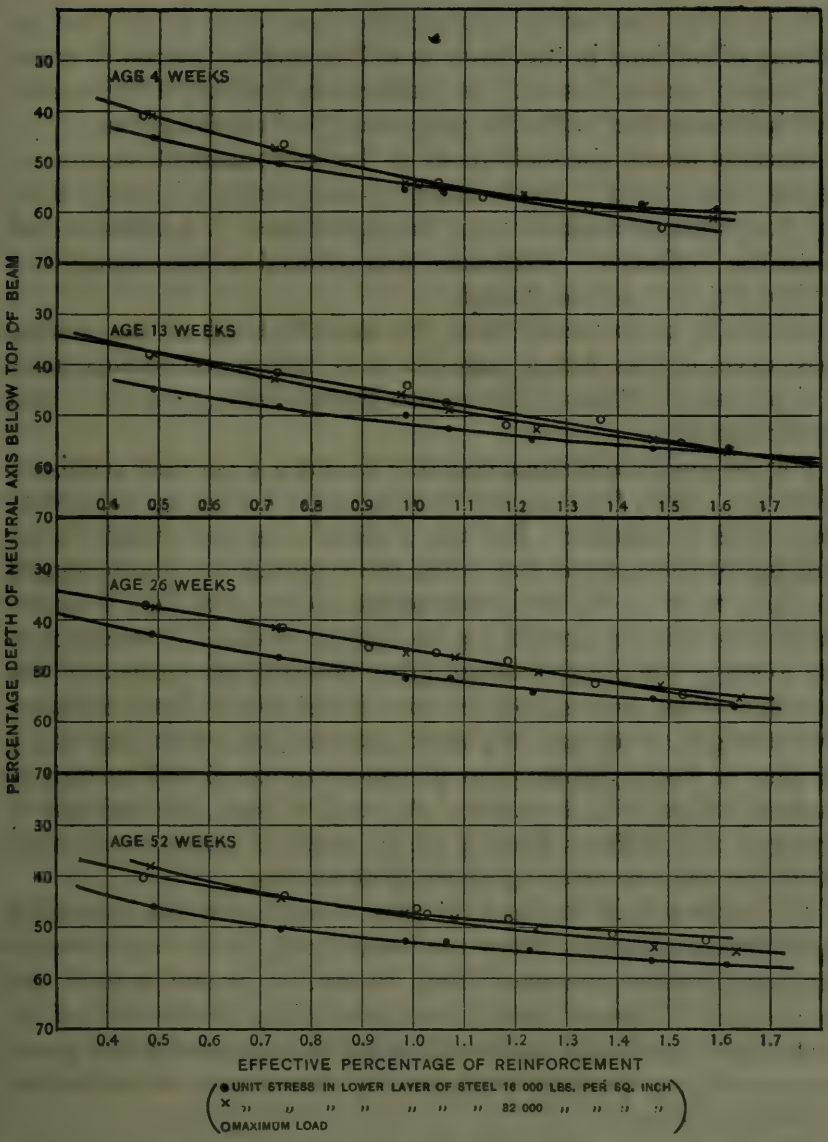

Fig. 9.—*Relation Between Position of Neutral Axis and Effective Percentage of Reinforcement for Cinder Concrete*

As was the case for the other curves, any error in the vertical placing of the bars in the beam as well as any instrumental errors in the deformeters inasmuch as it affects the position of the neutral axis influences the "effective percentage" of reinforcement.

Since, however, the yield point of the reinforcement used in the beams varied from 35 000 to about 42 000 pounds per square inch, the possibility of another error was introduced at maximum load when the "effective" percentage was reduced to correspond with a yield point of 40 000 pounds.

As might be expected from the upward bend of the neutral axis curves in Figs. 6 to 9, pages 62 to 65, the 32 000 pounds curve is in all cases well above the 16 000 pounds curve for 0.5 per cent reinforcement.

For the gravel and stone concrete having 1.6 per cent reinforcement the 4-week tests appear in one group and the 13, 26, and 52 week tests in another. For the 4-week tests the change in the position of the neutral axis when the stress in the reinforcement increases from 16 000 to 32 000 pounds per square inch is appreciably less than for ages of 13, 26, and 52 weeks. A reference to the average compressive stress gross deformation curves for the cylinders (Figs. 37 to 40, pp. 111 to 114) and the ultimate compressive strength at the age of 4 weeks as contrasted with that at 13, 26, and 52 weeks, Tables 33 to 36, pages 129 to 136, will furnish an explanation for this behavior. As may be seen, the increase in strength and stiffness from 4 to 13 weeks is quite appreciable, while the increase after 13 weeks is much less.

The tendency of the neutral axis to rise with the increasing development of cracks below the neutral axis as the unit stress in the reinforcement changes from 16 000 to 32 000 pounds per square inch is therefore partly counteracted by the lowering of the neutral axis, due to the uniformly changing stress conditions above the neutral axis, after the yield point of the concrete in compression has been reached.

When the age of 13 weeks is reached the concrete above the neutral axis has apparently increased sufficiently in strength and stiffness to make the development of cracks below the neutral axis the only factor in determining the change in its position.

This action is even more clearly brought out by the tests on the cinder concrete. For example, the 4-week tests on cinder concrete, below an effective percentage of about 1.1, shows that the neutral axis rises as the unit stress in the reinforcement increases from 16 000 to 32 000 pounds, the amount of the rise, however, steadily decreasing to zero at this percentage. For percentages of reinforcement above 1.1 the distance of the neutral axis below the top of the beam increases when the stress in the reinforcement changes from 16 000 to 32 000 pounds per square inch—the amount of the change increasing regularly as the percentage of reinforcement increases.

This lowering of the neutral axis above a reinforcement of 1.1 per cent is quite noticeable at maximum load, and would indicate that the ultimate compressive strength of the concrete has been almost developed. The individual tests at four weeks on cinder concrete having 1.50, 1.75 and 2 per cent nominal reinforcement present all the characteristics of the proximity or presence of a compression failure, becoming more marked as the percentage of reinforcement increases. From an examination of representative deformation curves for cinder concrete for the upper fiber it is seen that the abrupt change in direction at maximum load, which is always indicative of a tension failure, is absent. The curves, on the contrary, are very regular, although the deformations increase rapidly near the maximum load. The deformations of the upper fiber, as might be expected when the low modulus of elasticity (1 610 000) is taken into consideration, are very large even for comparatively low loads and continue to increase until near maximum load the increase in deformation is so great, for a small increase in load that the curves are practically horizontal.

Table 36, page 136, shows that the ultimate strength of cinder concrete at the age of 4 weeks as based on the tests of the cylinders is 1647 pounds per square inch.

Fig. 21, page 95, showing the relation between the "effective" percentage of reinforcement and the unit compressive stress in the extreme upper fiber, gives a unit compressive stress equal to 1750 pounds per square inch for 1.6 per cent reinforcement. This figure also indicates that at maximum load the unit compressive

stress in the extreme upper fiber for all percentages of reinforcement greater than 1 per cent is nearly equal to the ultimate strength of the concrete.

Fig. 9, page 65, showing the variation of position of the neutral axis with the "effective" per cent at the age of 13 weeks, brings out clearly the effect of the increase in strength and stiffness with age. At the age of 4 weeks it is seen that the depth of the neutral axis below the top of the beam remains constant for all intensities of loading for a percentage of reinforcement of 1.1.

For the 13-week tests this same condition is seen to occur at about 1.6 per cent, while for all percentages below this amount the distance of the neutral axis below the top of the beam decreases as the unit stress in the reinforcement increases.

Examining Table 36, page 136, and Fig. 21, page 94, it is seen that even at the age of 13 weeks the ultimate strength of the concrete in compression is approached when the amount of the reinforcement is 1.6 per cent.

All data illustrated in part by representative curves (Figs. 41 to 45, facing page 32) show the concrete still increasing in strength and stiffness for ages of 26 and 52 weeks, the latter figure being nearly similar in outline to those for the stone and gravel concretes at an age of 4 weeks, although the neutral axis for the cinder concrete is, of course, lower, due to the lower modulus of elasticity.

Table 27 has been prepared to show the distance of the neutral axis below the top of the beam for every age and aggregate and for 0.5 and 1.6 per cent "effective" reinforcement with stresses of 16 000 and 32 000 pounds per square inch respectively. These percentages read directly from the figures were chosen since they are the maximum values and minimum values that are common to all of Figs. 6 to 21, pages 62 to 95, and permit rough comparison of the tests to be made.

While it appears that age has an influence on the absolute position of the neutral axis for the purpose of comparison the percentage distance below the top of the beam has been averaged for all four ages and tabulated in Table 27, since the difference between stone and gravel concretes and cinder concrete is quite marked.

Table 27.—Percentage Depth of Neutral Axis Below Top of Beam, Based on Effective Depth

Unit Stress in Lower Layer of Reinforcement, 16 000 Pounds

Age, in Weeks	Granite		Gravel		Limestone		Cinders	
	Effective Percentage of Reinforcement		Effective Percentage of Reinforcement		Effective Percentage of Reinforcement		Effective Percentage of Reinforcement	
	0.5	1.6	0.5	1.6	0.5	1.6	0.5	1.6
4	34.5	46.5	32.5	44.0	33.5	48.0	45.5	60.0
13	35.5	45.0	32.5	43.0	34.5	46.0	45.0	57.0
26	32.0	44.0	33.0	42.0	33.5	44.0	43.5	57.0
52	32.5	44.5	33.0	44.0	31.0	44.5	46.0	57.5
Average	33.6	45.0	32.8	43.2	33.1	45.9	45.0	57.9

Unit Stress in Lower Layer of Reinforcement, 32 000 Pounds

4	29.0	45.0	29.0	42.0	29.0	46.0	41.0	61.5
13	29.0	40.5	26.5	39.0	28.5	43.0	38.0	57.0
26	27.0	40.0	26.0	38.0	28.0	40.0	37.5	55.0
52	27.5	40.0	26.5	39.0	25.0	41.0	38.0	55.0
Average	28.1	41.4	27.0	39.5	27.6	42.5	38.6	57.1

Table 28.—Relation Between Distance of Neutral Axis Below Top of Beam and Relative Value of Modulus of Elasticity

Kind of Aggregate	Average Ratio of Moduli of Elasticity Cinders=Unity	Stress in Reinforcement 16 000 Pounds Per Square Inch		Stress in Reinforcement 32 000 Pounds Per Square Inch	
		Effective Percentage of Reinforcement		Effective Percentage of Reinforcement	
		0.5	1.6	0.5	1.6
Gravel	2.63	32.8	43.2	27.0	39.5
Granite	2.37	33.6	45.0	28.1	41.4
Limestone	2.13	33.1	45.9	27.6	42.5
Average	2.38	33.2	44.7	27.6	41.1
Cinders	1.00	45.0	57.9	38.6	57.1
Ratio cinders to rock		1.36	1.30	1.40	1.39

The values in column 2 of this table were obtained from Tables 33 to 36, pages 129 to 136, by averaging the ratios of the moduli of elasticity calling that of cinders which is the lowest equal to unity. The change in the position of the neutral axis below the top of the beam is not influenced in direct proportion to the modulus of elasticity, the neutral axis for different concretes changing much less rapidly than the corresponding moduli of elasticity.

The values in this table have been arranged in decreasing order of the magnitude of the ratio of the moduli of elasticity, the stone and gravel concretes being grouped together, while the cinder concrete is shown separately.

The average ratio for stone and gravel concrete to cinder concrete is 2.38, which is about 4.5 times the change in that of the stone and gravel concrete. Bearing this in mind, it may reasonably be expected that the difference between the distance of the neutral axis below the top of the beam for cinder concrete and that for stone and gravel concrete is greater than that found in the stone and gravel concrete group. From the table this is seen to be the case, the ratio of the depth to the neutral axis for cinder concrete to that for stone and gravel concrete varying from 1.30 to 1.40, with an average value of 1.36.

Table 29.—Comparison of Computed and Observed Values of K for 0.5 Per Cent and 1.6 Per Cent "Effective Reinforcement."

Age in Weeks	Granite					Gravel					Limestone					Cinders				
	K in Per Cent for the Following Percentage of Reinforcement					K in Per Cent for the Following Percentage of Reinforcement					K in Per Cent for the Following Percentage of Reinforcement					K in Per Cent for the Following Percentage of Reinforcement				
	[14] N	0.5		1.6		N	0.5		1.6		N	0.5		1.6		N	0.5		1.6	
		Computed	Observed	Computed	Observed		Computed	Observed	Computed	Observed		Computed	Observed	Computed	Observed		Computed	Observed	Computed	Observed
4	6.99	25.0	29.0	40.0	45.0	6.52	24.0	29.0	39.0	42.0	8.36	27.0	29.0	43.0	46.0	18.63	37.0	41.0	56.0	62.0
13	6.77	25.0	29.0	40.0	41.0	6.49	24.0	27.0	39.0	39.0	7.88	26.0	29.0	42.0	43.0	16.48	36.0	38.0	54.0	57.0
26	6.70	25.0	27.0	39.0	40.0	5.73	23.0	26.0	37.0	38.0	6.96	25.0	28.0	40.0	40.0	14.15	34.0	38.0	52.0	55.0
52	6.29	24.0	28.0	39.0	40.0	5.56	23.0	27.0	37.0	39.0	6.59	24.0	25.0	40.0	41.0	14.22	34.0	38.0	52.0	55.0
Average		24.7	28.2	39.5	41.5		23.5	27.2	38.0	37.0		25.5	27.8	41.2	42.5		35.2	38.7	53.5	57.2

[14] N=Ratio of modulus of elasticity of steel (30 000 000) to the average initial modulus of elasticity of concrete. (Tables 33 to 36.)

While it is somewhat foreign to the purpose of this bulletin to enter into any theoretical discussions, and while it has been the aim to adhere strictly to a presentation and discussion of experimental results, the preceding table giving the computed and experimental position of the neutral axis is of interest.

The experimental or observed value of the depth of the neutral axis below the top of the beam has been read from the 32 000 pounds stress curve. (Figs. 6 to 9.) Since the formula, by which the computed values of the neutral axis were obtained, is based in part on the assumption that the concrete below the neutral axis has no tensile resistance, the observed values, with which the computed values are to be compared, should be obtained at a stage during the test when the beam most nearly approximates the conditions assumed in the formula. Since the maximum load values are in no case as accurate as could be desired, the computed values have been compared with the observed values for a stress of 32 000 pounds per square inch in the lower layer of the reinforcement.

The general formula for proportionate distance of the neutral axis below the top of the beam is as follows:

$$K = \sqrt{\frac{2pn}{1-\frac{1}{3}q} + \left[\frac{pn}{1-\frac{1}{3}q}\right]^2} - \frac{pn}{1-\frac{1}{3}q}$$

K = proportionate depth of the neutral axis below top of beam.

P = "Effective" percentage of reinforcement.

n = ratio of the modulus of elasticity of the reinforcement to the initial modulus of elasticity of the concrete.

q = ratio of unit compressive deformation developed in the upper fiber of the beam to the ultimate unit compressive deformation of the concrete.

In this formula, as in others, q has been made equal to $\frac{1}{2}$.

The values for the four ages have been averaged. The computed value is in all except one case less than the observed value. In examining this table it should be remembered that in the theoretical formula q has been retained equal to $\frac{1}{2}$, irrespective of the kind of concrete, and further that the assumed condition of total absence of tensile resistance below the neutral axis is not true.

(2) **Variation of $\frac{M}{bd^2}$ with "Effective" Percentage of Reinforcement.**—The data plotted in Figs. 10 to 13 was obtained in tables similar to Table 27, page 69. An inspection of these diagrams shows that the variation of $\frac{M}{bd^2}$ with "effective" per cent of reinforcement can be represented sufficiently well by a straight line. A straight line has therefore been drawn through every group of points, one for a unit stress in the lower layer of reinforcement equal to 16 000 pounds, another for 32 000 pounds, and a third at maximum load. The curve for 32 000 pounds per square inch is always well above that for 16 000 pounds, and the direction of both is such that they would converge at about the same point for zero percentage of reinforcement. This is, however, not the case for the line drawn at maximum load. In many cases the line crosses that for 32 000 pounds stress in the reinforcement, seeming to indicate that the $\frac{M}{bd^2}$ or load carried at "maximum" load was actually less than that carried for a stress of 32 000 pounds per square inch in the reinforcement. As was pointed out in the preparation of Table 27, page 69, the "effective" percentage of reinforcement at maximum load had to be modified, due to the fact that the yield point of the reinforcement used varied from 35 000 to 42 000 pounds per square inch. Since a unit stress of 40 000 pounds was taken as a basis for comparison, the effective per cent of all beams having reinforcement of a higher yield point was increased, when corrected, above what it would be if based only on the position of the neutral axis, while if the reinforcement were of lower yield point it would be decreased. The effect of such an increase in percentage is to move the plotted point over horizontally a distance which is in several cases great enough to cause the maximum load line to intersect that for a stress of 32 000 pounds in the reinforcement.

This behavior would seem to throw suspicion on the correctness of the assumptions made in the preparation of the data used in plotting this line. In studying any of these diagrams, too much emphasis can not be laid on the necessity for remembering how

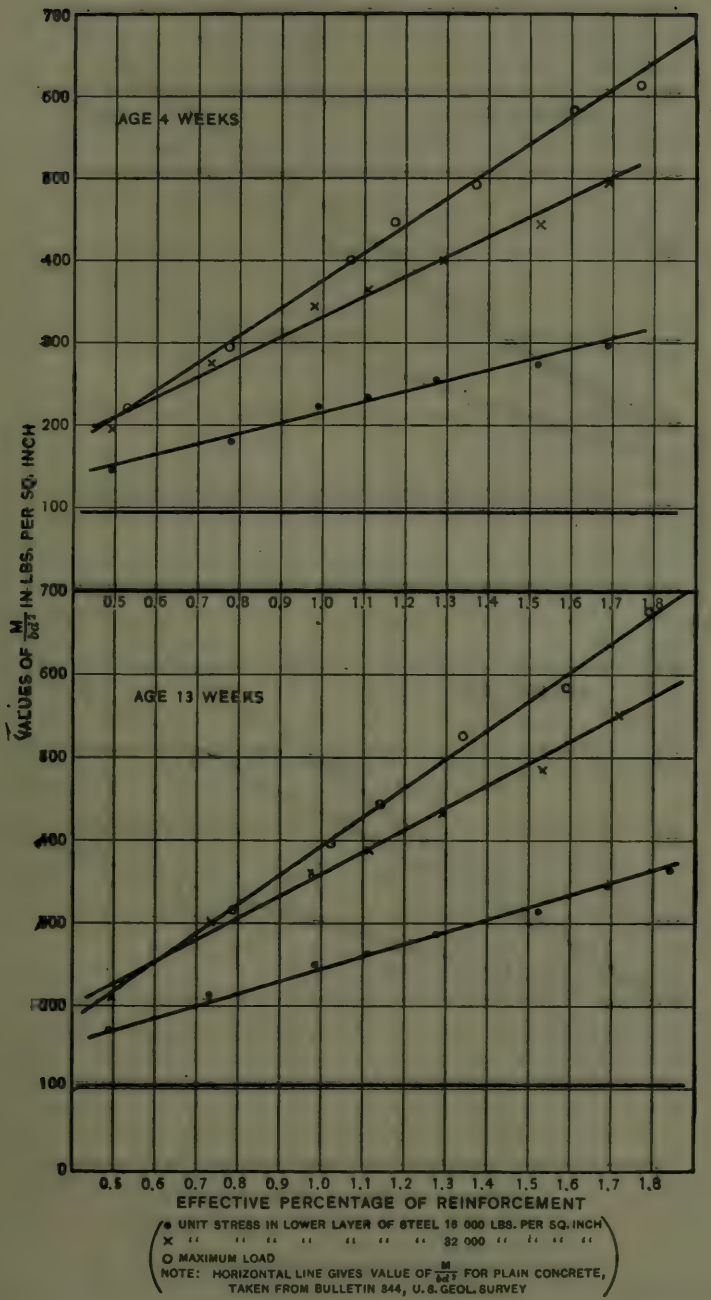
AGE 4 WEEKS
AGE 13 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
• UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " 32 000 " " " "
O MAXIMUM LOAD
NOTE: HORIZONTAL LINE GIVES VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U.S. GEOL. SURVEY

Fig. 10a.—*Relation between* $\frac{M}{bd^2}$ *and Effective Percentage of Reinforcement for Granite Concrete*

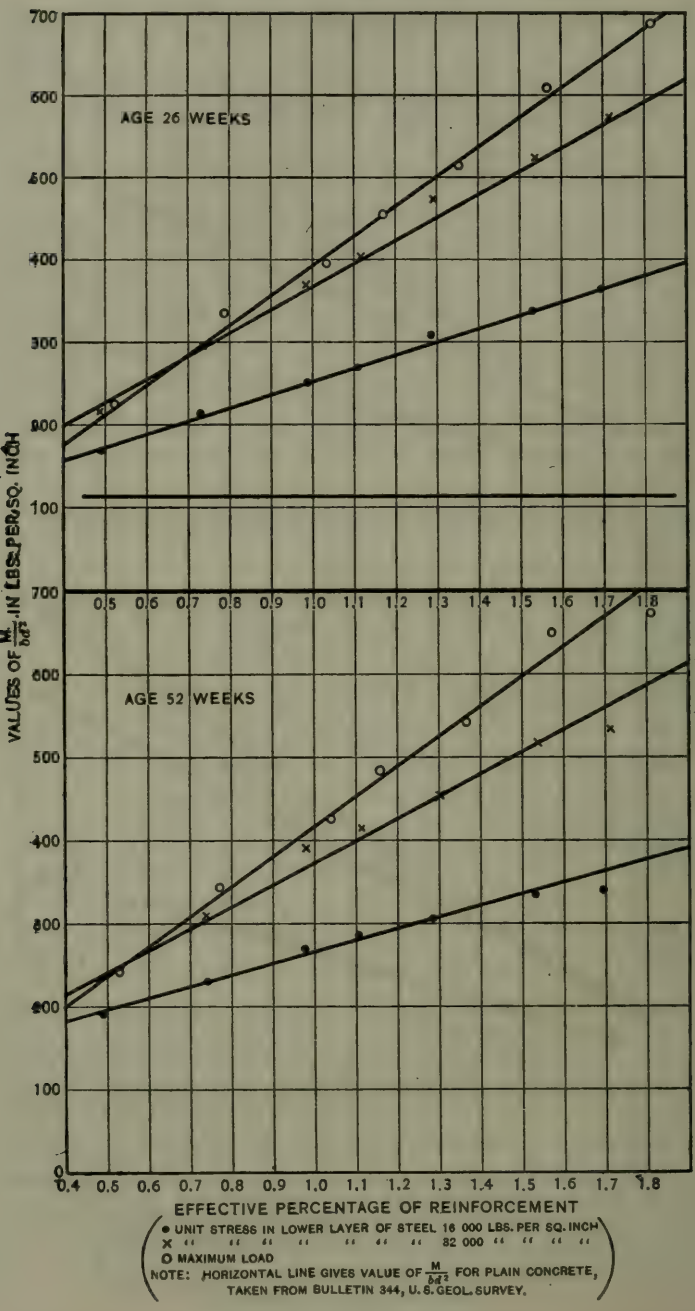
AGE 26 WEEKS
AGE 52 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
• UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " 32 000 " " " "
O MAXIMUM LOAD
NOTE: HORIZONTAL LINE GIVES VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U. S. GEOL. SURVEY.

Fig. 10b.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage of Reinforcement for Granite Concrete*

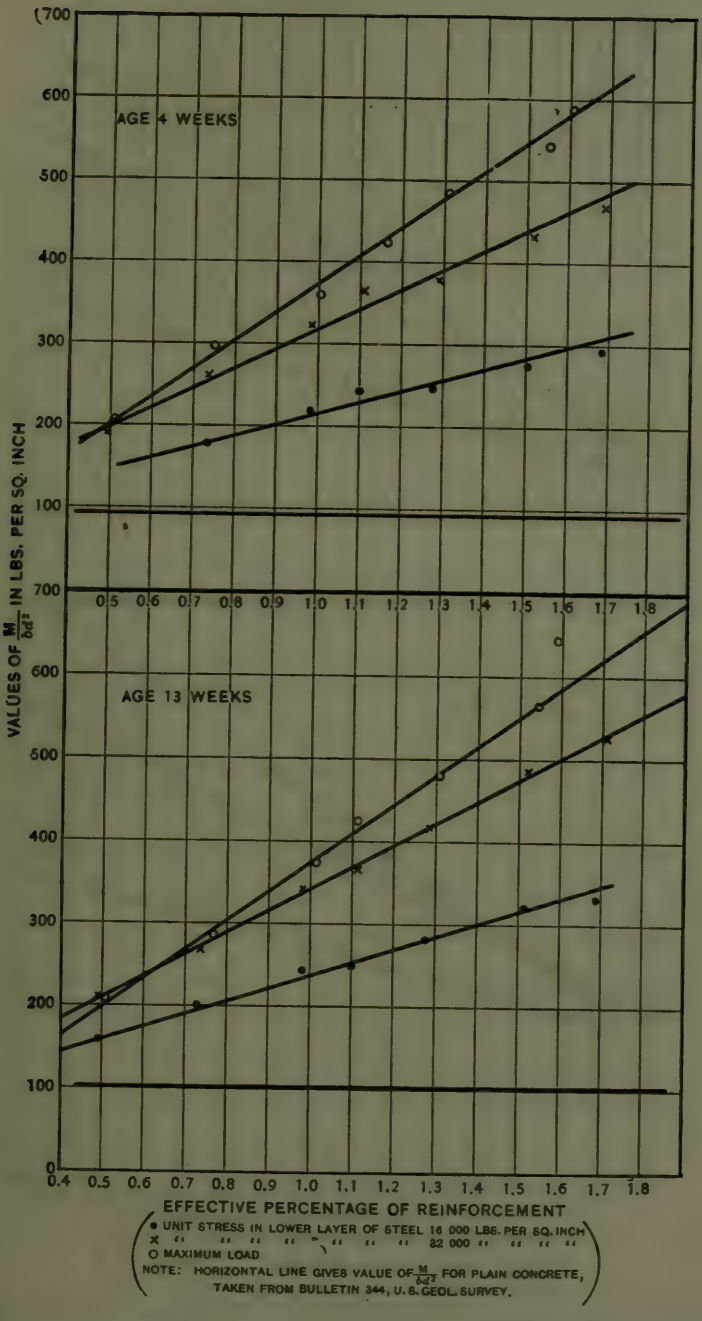
AGE 4 WEEKS
AGE 13 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
• UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " 32 000 " " " "
O MAXIMUM LOAD
NOTE: HORIZONTAL LINE GIVES VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U. S. GEOL. SURVEY.

Fig. 11a.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage of Reinforcement for Limestone Concrete*

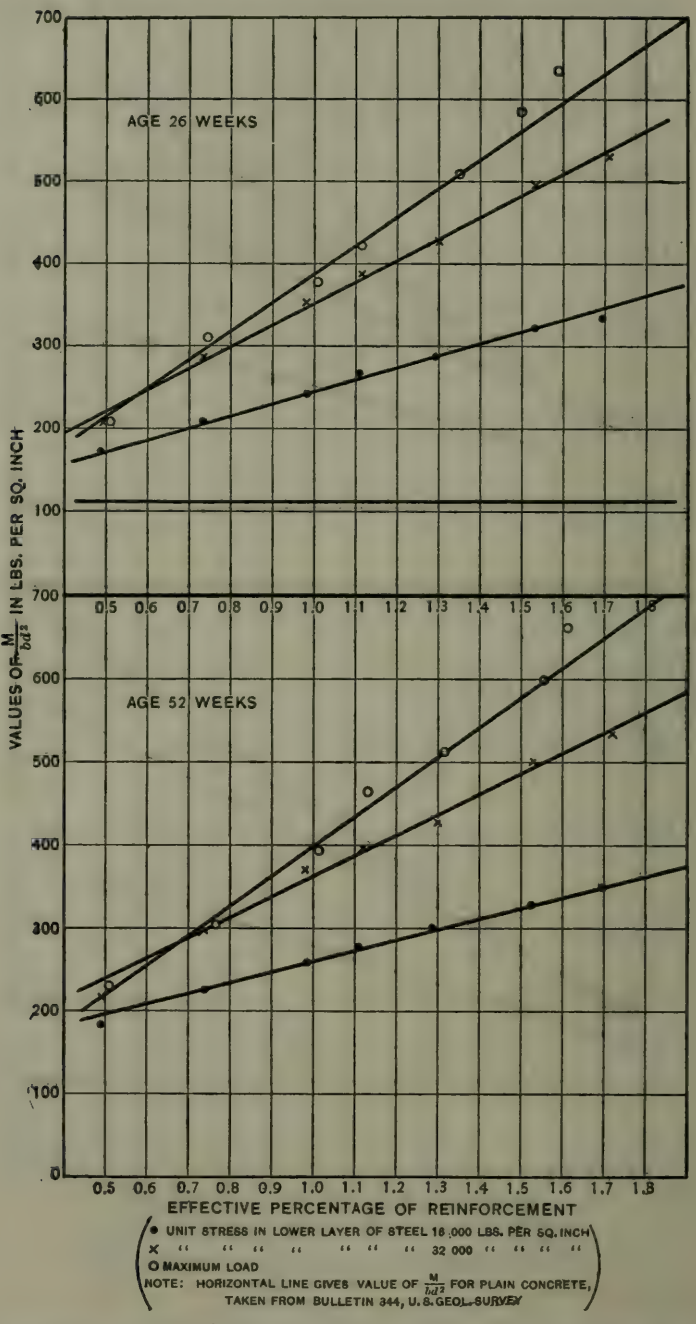
AGE 26 WEEKS
AGE 52 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
• UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " 32 000 " " " "
O MAXIMUM LOAD
NOTE: HORIZONTAL LINE GIVES VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U. S. GEOL. SURVEY

Fig. 11b.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage of Reinforcewent for Limestone Concrete*

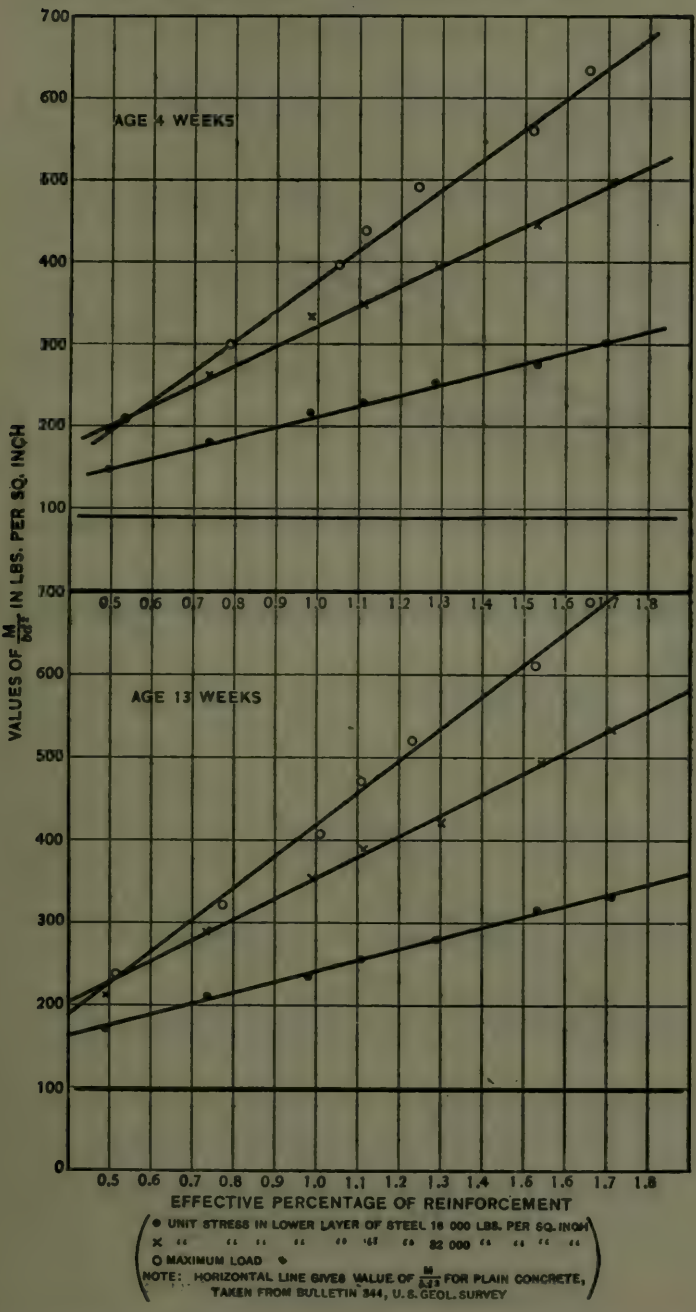
AGE 4 WEEKS
AGE 13 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
● UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " 32 000 " " " "
○ MAXIMUM LOAD
NOTE: HORIZONTAL LINE GIVES VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U. S. GEOL. SURVEY

Fig. 12a.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage of Reinforcement for Gravel Concrete*

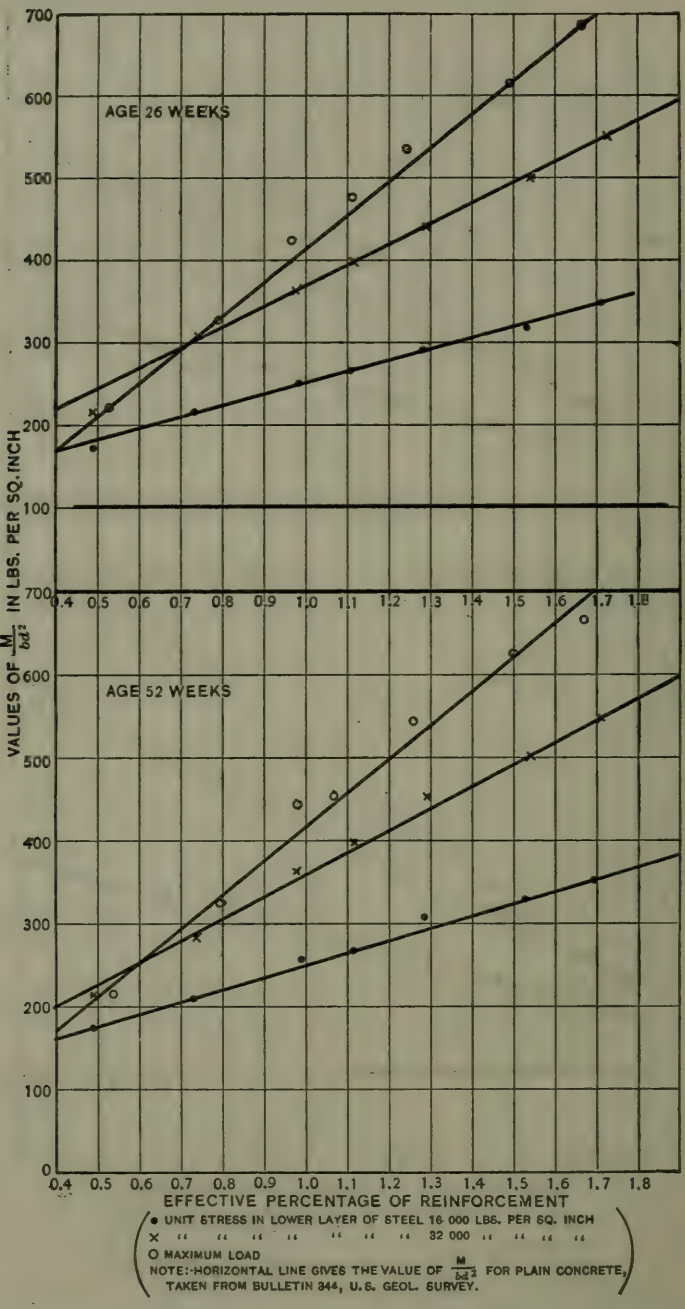
AGE 26 WEEKS
AGE 52 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
• UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " " 32 000 " " " "
O MAXIMUM LOAD
NOTE:-HORIZONTAL LINE GIVES THE VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U.S. GEOL. SURVEY.

Fig. 12b.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage of Reinforcement for Gravel Concrete*

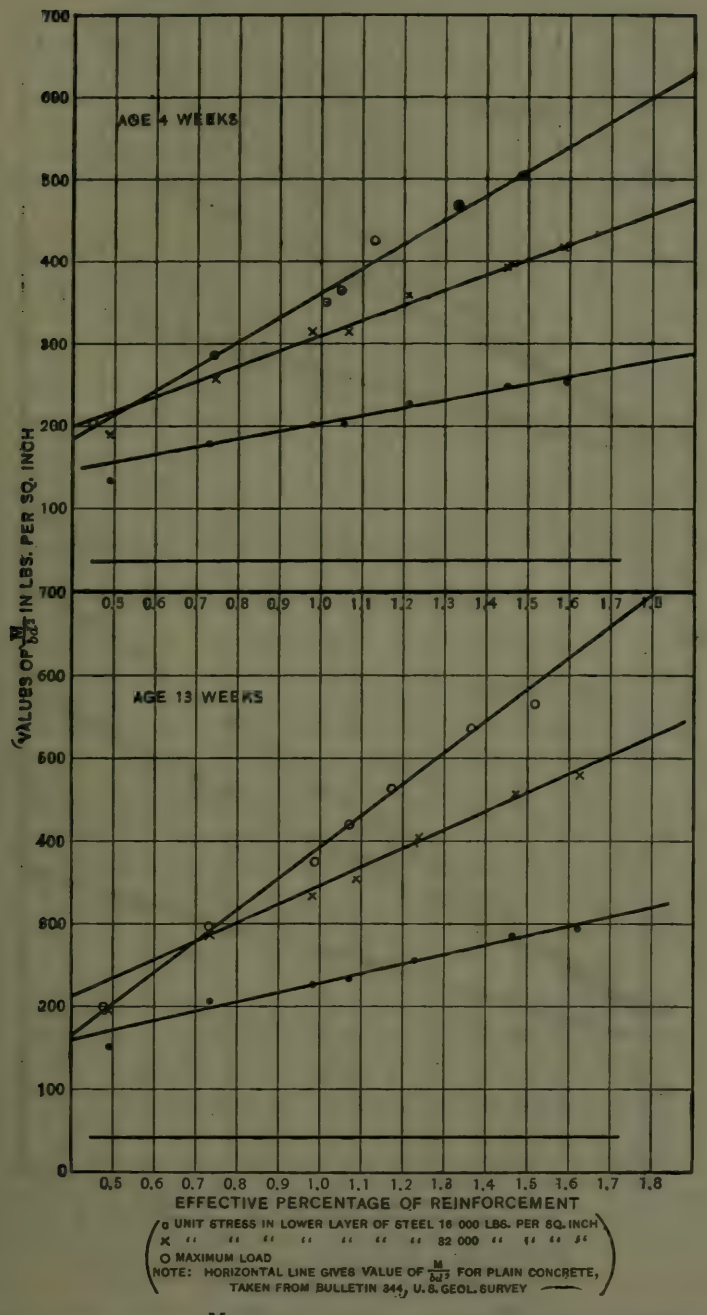
AGE 4 WEEKS
AGE 13 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
o UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " 32 000 " " " "
O MAXIMUM LOAD
NOTE: HORIZONTAL LINE GIVES VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U. S. GEOL. SURVEY

Fig. 13a.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage for Reenforcement of Cinder Concrete*

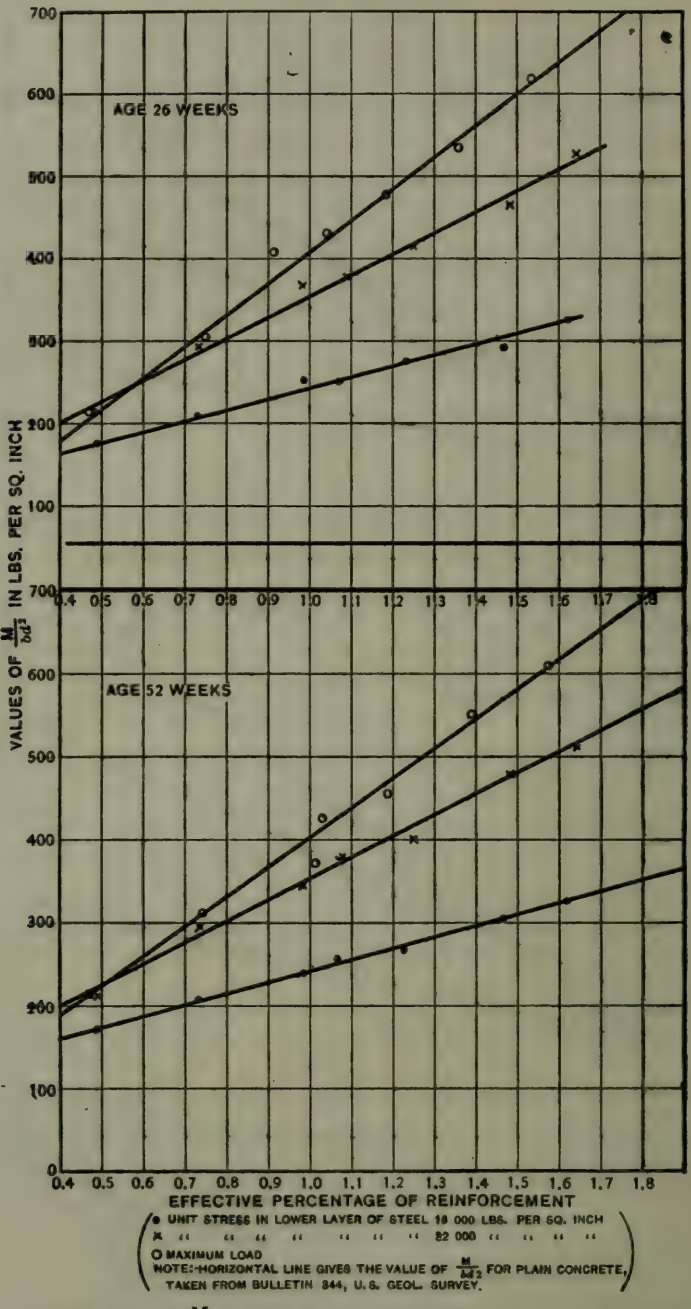
AGE 26 WEEKS
AGE 52 WEEKS
VALUES OF $\frac{M}{bd^2}$ IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
• UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " 22 000 " " " "
O MAXIMUM LOAD
NOTE:-HORIZONTAL LINE GIVES THE VALUE OF $\frac{M}{bd^2}$ FOR PLAIN CONCRETE, TAKEN FROM BULLETIN 344, U.S. GEOL. SURVEY.

Fig. 13b.—*Relation Between* $\frac{M}{bd^2}$ *and Effective Percentage of Reenforcement for Cinder Concrete*

the various values used were obtained. The value of $\frac{M}{bd^2}$ is, of course, almost correct since it is based on a load which could be accurately determined and on dimensions, span, position of load points, breadth, and depth, all of which can be accurately measured.

As has already been pointed out this was not the case in determining the "effective" percentage of reinforcement. There is also the possibility that for the same "effective" percentage all concentrated in the lower layer in one case and in another distributed in two layers, there may be sufficient difference in behavior in the action of the beam under load, to cause some of the more or less erratic values that are noticeable.

The lines for 16 000 and 32 000 pounds per square inch in the reinforcement are therefore in one group and are comparable among themselves, while the line for maximum load can only be compared with other maximum load lines.

Examining the values for $\frac{M}{bd^2}$ at an "effective" percentage of reinforcement of 0.5 and 1.6 per cent and for a stress of 16 000 and 32 000 pounds per square inch in the reinforcement and contrasting the 4-week with the 13-week tests the effect of the character of the compressive stress gross deformation curve on the resistance of the beam is very generally brought out. At a reinforcement of 0.5 per cent for which the intensity of loading does not cause compressive stresses in the concrete much above the yield point, at the age of 4 weeks, the increase in $\frac{M}{bd^2}$ at 13 weeks is less than for 1.6 per cent reinforcement for which in many cases the compressive stress developed in the upper fiber was considerably greater than the yield point. This is particularly true for a unit stress in the steel of 32 000 pounds per square inch.

The $\frac{M}{bd^2}$ for 32 000 pounds per square inch is not exactly twice that for a stress of 16 000 pounds per square inch. This is probably due to the fact that a beam without reinforcement, 8 by

11 inches in section, has itself considerable resistance to flexure, which must be added to that due to the introduction of reinforcement.

Bulletin 344 [15] gives tests on concrete beams without reinforcement, having the same gross 8 by 11 inch section that was used in the reinforced beam series reported in this bulletin. A portion of the tests of the first series was of beams of a constant 12-foot span, while a secondary portion included beams of variable spans which consisted of the larger portion of the 12-foot span after rupture. A summary of the results of the tests on the 12-foot beams is given in Table 8, pages 36–40, while that for the beams of variable span is given in Table 9, pages 42–46 of the above bulletin. Column 19, Table 8, contains the maximum total $\frac{M}{bd^2}$ for the 12-foot beams, while column 20, Table 9, gives the same information for the variable beams. Since the value of $\frac{M}{bd^2}$ is independent of the span and the conditions of loading these values have been averaged.

Since a medium consistency was used in the reinforced beams, only the $\frac{M}{bd^2}$ for the beams without reinforcement of medium consistency has been used. As was previously indicated the value of $\frac{M}{bd^2}$ for these beams was based on a depth of 11 inches, for which $bd^2 = 968$. The $\frac{M}{bd^2}$ which is plotted on Figs. 6 to 21, pages 62 to 95, has, however, been based on the depth to the reinforcement which is 10 inches, making $bd^2 = 800$.

The value of $\frac{M}{bd^2}$ as given in Tables 8 and 9, Bulletin 344 [15] should therefore be multiplied by $\frac{968}{800} = 1.21$ to make them directly comparable with the values plotted in the figures.

Where the gravel and stone concretes were identical in both beam series, there is a tendency which seems to indicate that the three lines should meet the common point of zero reinforcement.

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[15] U. S. Geological Survey.

If we use this line as a datum, the resistance of the beam to flexure is nearly proportional to the stress in the reinforcement—that is, the distance on the ordinate from the datum line to the 32 000-pound line is nearly equal to twice the distance to the 16 000-pound line.

It has already been pointed out in Bulletin 344,[15] and called attention to in the present bulletin, in discussing the elongation of the lower fiber at first crack, that the proportion of the cinder concrete was a 1 : 2 : 5 volume-proportion instead of 1 : 2 : 4. The influence of this difference is clearly seen in the position of the line for the cinder concrete in beams without reinforcement in Figs. 10 to 13, pages 73 to 80.

These figures again bring out clearly the fact, to which attention has already been called, in discussing the ratio of the external bending moment and the internal resisting moment, based on the measured stress in the reinforcement (Tables 6 to 21, column 22, following page 128), that the strength of the concrete in tension below the neutral axis has an appreciable effect on the resistance of the beam.

(3) **Variation of the Deflection at Center of Span with Effective Percentage of Reinforcement.**—Figs. 14 to 17, pages 86 to 90, showing the relation existing between the deflection of the center of the beam, in inches, and the effective percentage of reinforcement for maximum load, and for stresses of 16 000 and 32 000 pounds per square inch, have been prepared from tabulated data similar to that shown in Table 45, columns 10, 11, 15, 16, 20 and 21.

With the explanation of the method of preparation of similar diagrams that has already been given, any further comments on these figures seem unnecessary. An interesting check on the accuracy of the measured deflections, as well as the deformation of the upper and the lower fiber, and consequently the position of the neutral axis, which is obtained directly from the last two, can be obtained by computing the deflection for a stress of 16 000 and 32 000 pounds in the reinforcement. The formula used neglects the weight of the beam, and is based on a beam loaded at the third

points only. The deflection at the center is obtained from the elastic curve, in the derivation of which the usual assumptions are made. The formula reduces to—

$$\Delta = \frac{220.8\, S}{E\ (1-k)}$$

Where Δ = deflection, in inches, at center of beam.
E = modulus of elasticity of reinforcement.
S = unit stress in reinforcement.
k = proportionate depth to neutral axis.

For $S = 32\ 000$ $\quad \Delta = \frac{0.235}{1-k}$

$S = 16\ 000$ $\quad \Delta = \frac{0.118}{1-k}$

With these formulas and the values of 'k' as given by Figs. 6 to 9, pages 62 to 65, as a basis, the following table has been prepared for percentages of 0.5 and 1.6 "effective" reinforcement.

The deflections are paralleled by those containing the values obtained from Figs. 14 to 17, which are based on the observed deflections. As will be seen there is a very satisfactory agreement between the observed and the computed values, which not only checks the observed values but also throws light on the degree of accuracy of the deformations.

An inspection of this table will show that for a given stress in the reinforcement the deflection is independent of the age. Since there is no apparent relation between deflection and age, the values in the above table have been averaged, and the average deflection for 32 000 pounds in the reinforcement compared with that for 16 000 pounds per square inch, in the last line of the table. The deflection is apparently not quite doubled, when the stress in the reinforcement is doubled. The average deflections for the stone and gravel concretes, and that for the cinder concrete, for 0.5 and 1.6 per cent reinforcement, have been roughly expressed in terms of the span in the following table.

Table 30.—Approximate Deflections, in Terms of the Span Length

Kind of Concrete	Stress in Reinforcement 16 000 Pounds		Stress in Reinforcement 32 000 Pounds	
	Effective Percentage of Reinforcement		Effective Percentage of Reinforcement	
	0.5	1.6	0.5	1.6
Stone and gravel	$\frac{1}{1000}$	$\frac{1}{720}$	$\frac{1}{500}$	$\frac{1}{360}$
Cinder	$\frac{1}{1000}$	$\frac{1}{600}$	$\frac{1}{500}$	$\frac{1}{300}$

Table 31.—Computed and Measured Deflection, in inches, at the Center of the Beam

Unit Stress in Lower Layer of Reinforcement 32 000 Pounds per Square Inch

Age, in Weeks	Granite				Gravel				Limestone				Cinders			
	Effective Percentage of Reinforcement				Effective Percentage of Reinforcement				Effective Percentage of Reinforcement				Effective Percentage of Reinforcement			
	0.5		1.6		0.5		1.6		0.5		1.6		0.5		1.6	
	Deflection															
	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed	Computed	Observed
4	0.33	0.30	0.43	0.40	0.33	0.31	0.41	0.39	0.33	0.30	0.44	0.41	0.40	0.37	0.60	0.56
13	.33	.31	.40	.38	.32	.29	.39	.38	.33	.32	.41	.40	.38	.34	.55	.51
26	.32	.31	.39	.40	.32	.25	.38	.37	.33	.31	.39	.38	.38	.34	.53	.51
52	.32	.29	.39	.39	.32	.28	.39	.39	.31	.29	.40	.38	.38	.33	.51	.52
Average	.33	.30	.40	.39	.32	.29	.39	.38	.33	.31	.41	.39	.39	.35	.55	.53

Unit Stress in Lower Layer of Reinforcement 16 000 Pounds per Square Inch

4	0.17	0.16	0.22	0.19	0.18	0.16	0.21	0.19	0.18	0.14	0.23	0.20	0.22	0.19	0.30	0.26
13	.18	.16	.21	.19	.18	.15	.21	.19	.18	.14	.22	.20	.21	.20	.27	.26
26	.17	.17	.21	.21	.18	.15	.20	.19	.18	.15	.21	.20	.21	.19	.27	.27
52	.18	.20	.21	.20	.18	.16	.21	.20	.17	.16	.21	.20	.22	.20	.27	.27
Average	.19	.17	.21	.20	.18	.16	.21	.19	.18	.15	.22	.20	.22	.20	.28	.27
Ratio $\frac{32\,000}{16\,000}$	1.53	1.76	1.90	1.95	1.78	1.81	1.86	2.00	1.83	2.06	1.86	1.95	1.77	1.75	1.96	1.96

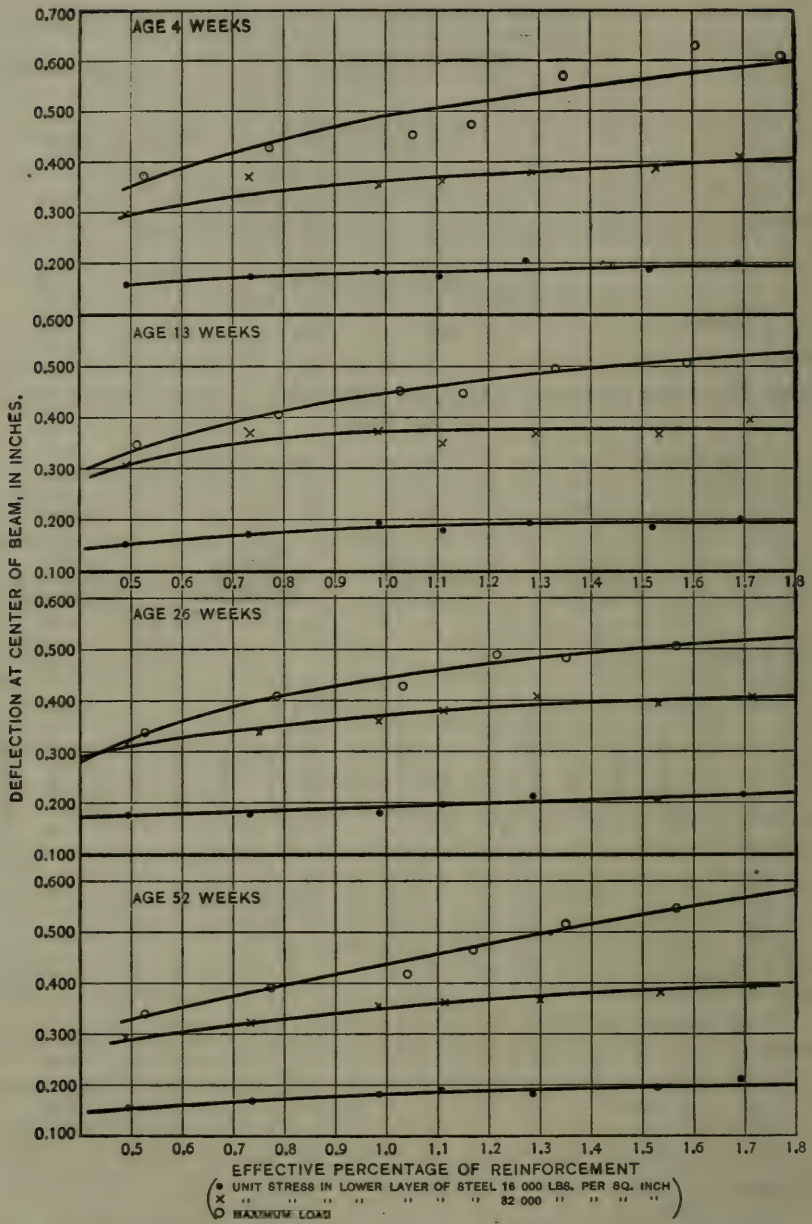
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
DEFLECTION AT CENTER OF BEAM, IN INCHES.
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8
EFFECTIVE PERCENTAGE OF REINFORCEMENT
UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
" " " " " " " 32 000 " " " "
MAXIMUM LOAD

Fig. 14.—*Relation Between Deflection of Beam and Effective Percentage of Reinforcement for Granite Concrete*

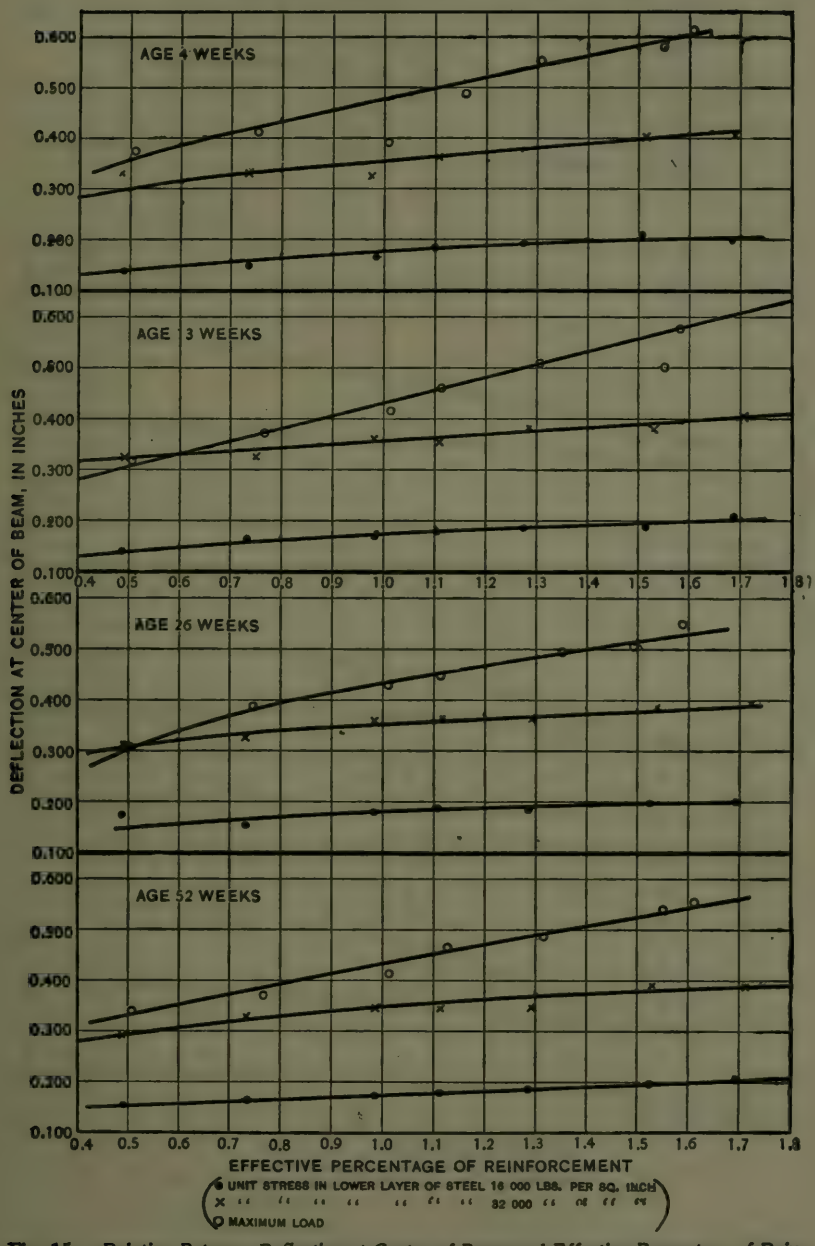
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
DEFLECTION AT CENTER OF BEAM, IN INCHES
0.600
0.500
0.400
0.300
0.200
0.100
0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8
EFFECTIVE PERCENTAGE OF REINFORCEMENT
● UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
× " " " " " " " " 32 000 " " " "
○ MAXIMUM LOAD

Fig. 15.—*Relation Between Deflection at Center of Beam and Effective Percentage of Reinforcement for Limestone Concrete*

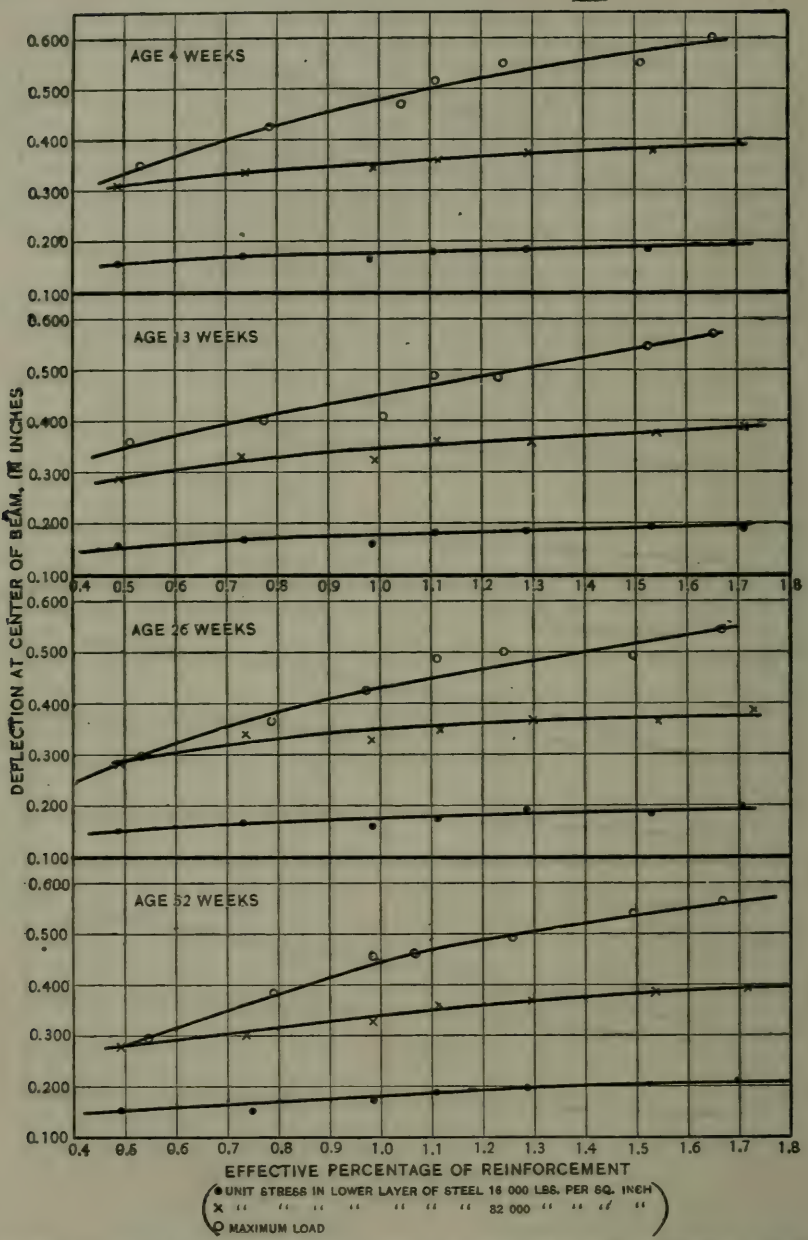
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
DEFLECTION AT CENTER OF BEAM, IN INCHES
0.600
0.500
0.400
0.300
0.200
0.100
0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8
EFFECTIVE PERCENTAGE OF REINFORCEMENT
UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
" " " " " " " 32 000 " " " "
MAXIMUM LOAD

Fig. 16.—*Relation Between Deflection at Center of Beam and Effective Percentage of Reinforcement for Gravel Concrete*

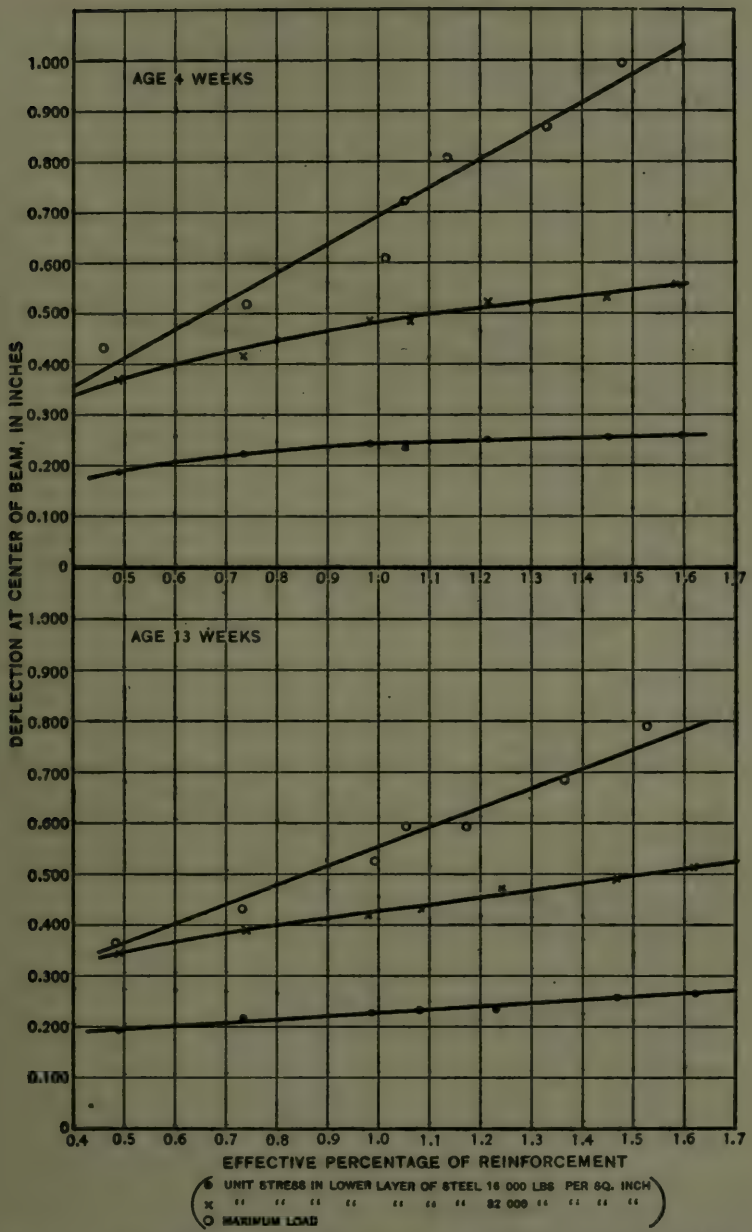

Fig. 17a.—*Relation Between Deflection at Center of Beam and Effective Percentage of Reinforcement for Cinder Concrete*

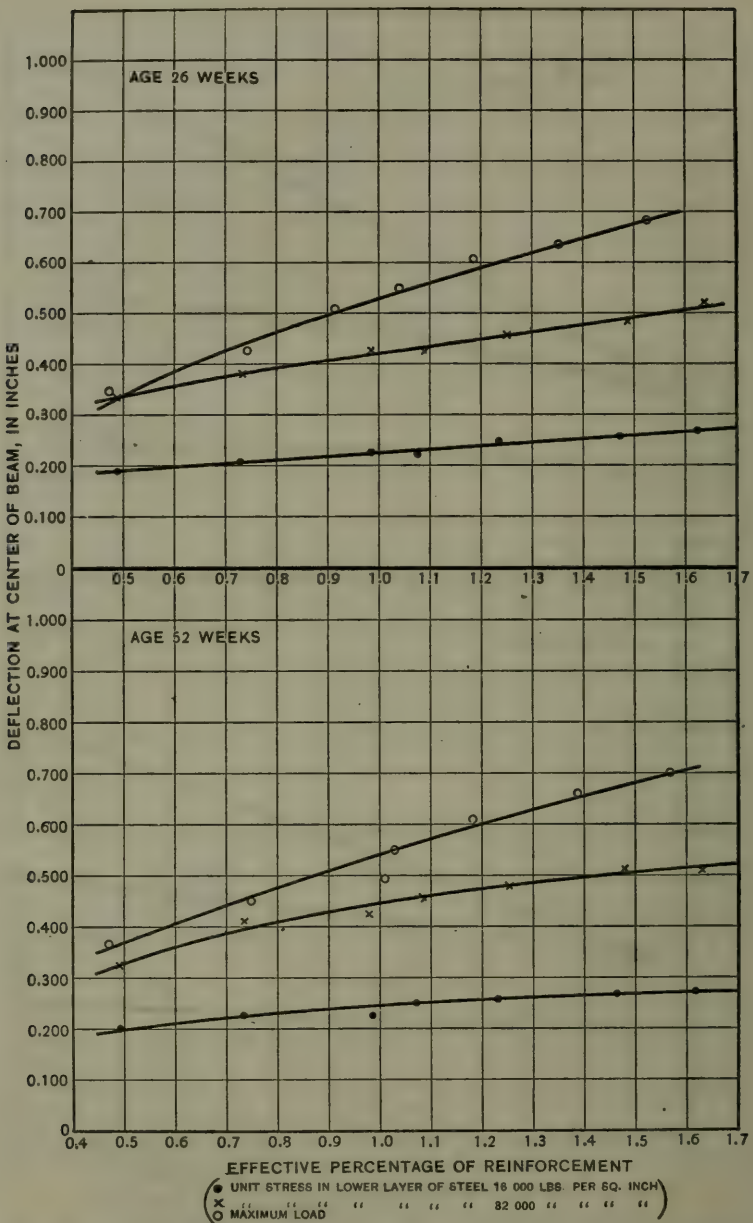

Fig 17b.—*Relation Between Deflection at Center of Beam and Effective Percentage of Reinforcement for Cinder Concrete*

(4) Variation of Compressive Stress in Extreme Upper Fiber with "Effective" Percentage of Reinforcement.—The data given in Table 26, columns 4, 10, 13, 16, 18 and 21, furnishes the basis for determining the relation between the unit compressive stress in the extreme upper fiber for maximum load, 16 000 pounds and 32 000 pounds per square inch in the lower layer of the reinforcement.

As has already been pointed out in explaining the preparation of Table 27, page 69, the unit deformation of the upper fiber could in but few cases be observed directly, and the values tabulated had therefore to be estimated from the upper fiber curves.

The average compressive-stress gross-deformation curves, Figs. 37 to 40, pages 111 to 114, are entered with the values of the unit compressive deformation, columns 4, 13, and 18, Table 26, and the corresponding unit compressive stress determined. This was plotted against the "effective" percentage of reinforcement, columns 10, 16, and 21, Table 26, in Figs. 18 to 21, pages 92 to 95.

An inspection of these figures will show that the group of points for each intensity of loading can be represented with sufficient accuracy by a straight line.

A summary of the unit compressive stress in the upper fiber for 0.5 and 1.6 per cent "effective reinforcement" and at a unit stress in the lower layer of reinforcement of 16 000 and 32 000 pounds has been made in the following table:

An inspection of this table will show the fallacy of the usual assumption, made in specifications, of the simultaneous occurrence of a unit compressive stress of 500 to 800 pounds per square inch in the upper fiber and a unit stress of 16 000 pounds in the reinforcement. A beam of cinder concrete with 0.5 per cent reenforcement and 4 to 13 weeks old is the only case which even approximates the assumed conditions. For all other aggregates and ages the unit stress in the upper fiber is from about two to four times as great as that assumed.

It should be noted, therefore, that if under actual conditions of loading a unit stress of 16 000 pounds is really developed in the reinforcement the stress in the upper fiber is at least 1000 pounds per square inch and in many cases is considerably greater.

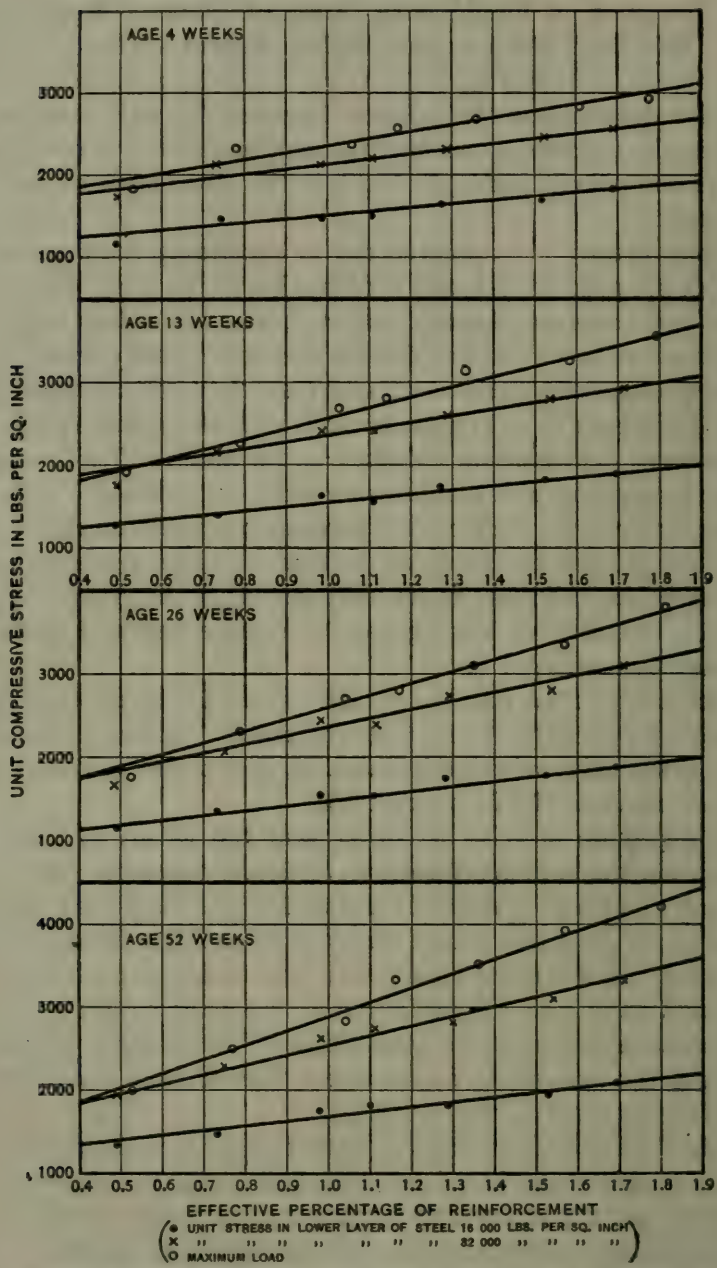
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
UNIT COMPRESSIVE STRESS IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
" " " " " " " 32 000 " " " "
MAXIMUM LOAD

Fig. 18.—*Relation Between Unit Compressive Stress in Upper Fiber and Effective Percentage of Reinforcement for Granite Concrete*

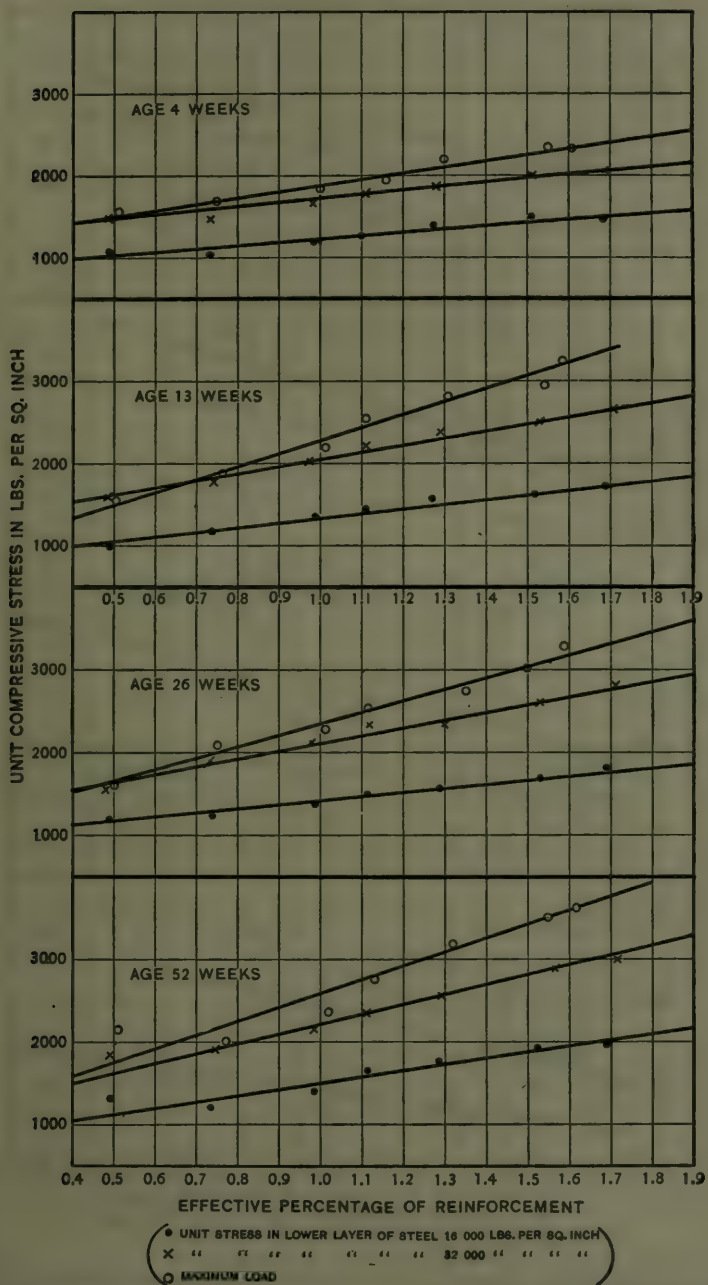
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
UNIT COMPRESSIVE STRESS IN LBS. PER SQ. INCH
3000
2000
1000
0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6 1.7 1.8 1.9
EFFECTIVE PERCENTAGE OF REINFORCEMENT
UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
" " " " " " " 32 000 " " " "
MAXIMUM LOAD

Fig. 19.—*Relation Between Unit Compressive Stress in Upper Fiber and Effective Percentage of Reinforcement for Limestone Concrete*

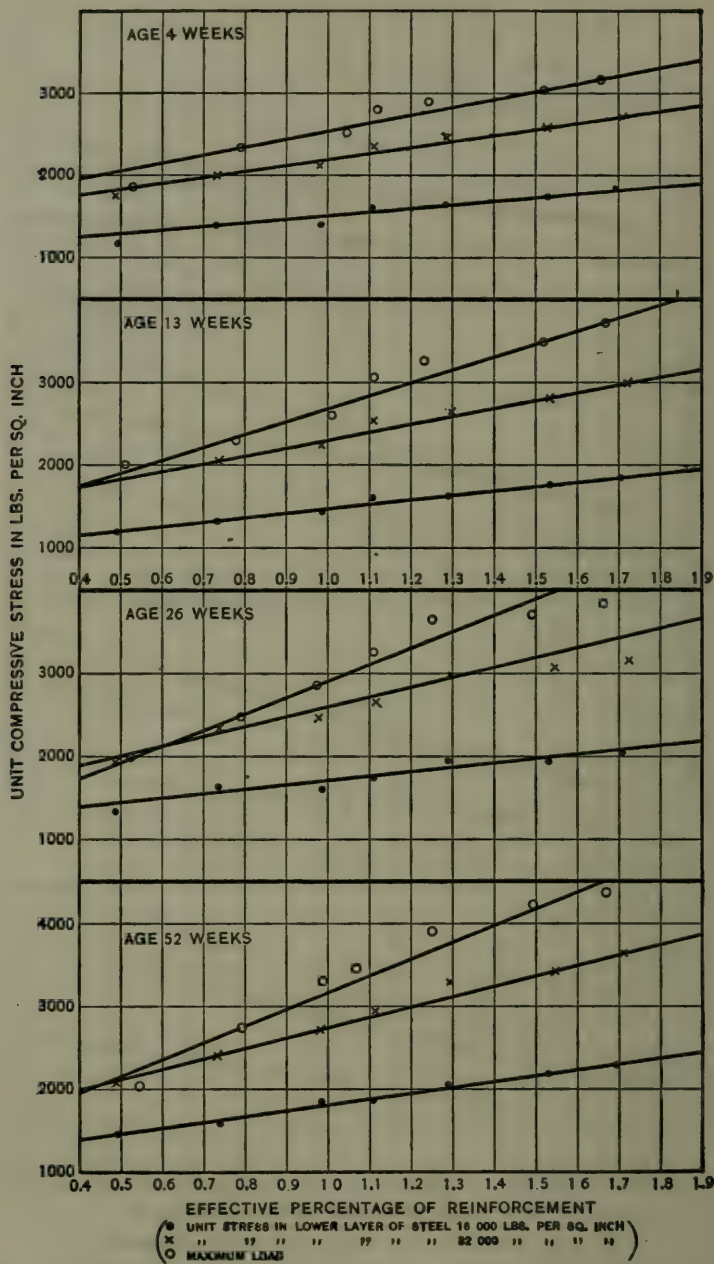
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
UNIT COMPRESSIVE STRESS IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
UNIT STRESS IN LOWER LAYER OF STEEL 16 000 LBS. PER SQ. INCH
" " " " " " 32 000 " " " "
MAXIMUM LOAD

Fig. 20.—*Relation Between Unit Compressive Stress in Upper Fiber and Effective Percentage of Reinforcement for Gravel Concrete*

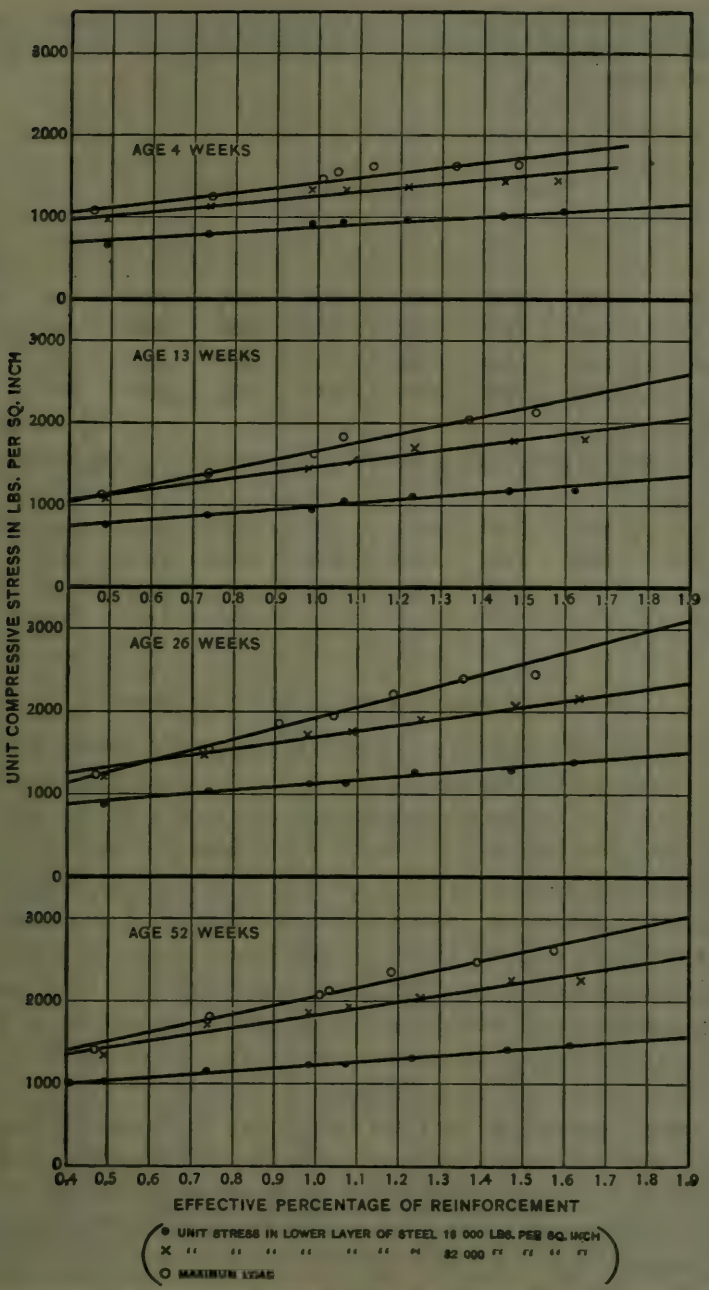
AGE 4 WEEKS
AGE 13 WEEKS
AGE 26 WEEKS
AGE 52 WEEKS
UNIT COMPRESSIVE STRESS IN LBS. PER SQ. INCH
EFFECTIVE PERCENTAGE OF REINFORCEMENT
UNIT STRESS IN LOWER LAYER OF STEEL 18 000 LBS. PER SQ. INCH
82 000
MAXIMUM LOAD

Fig. 21.—*Relation Between Unit Compressive Stress in Upper Fiber and Effective Percentage of Reinforcement for Cinder Concrete*

Table 32.—Summary of unit Compressive Stress in the Upper Fiber of Beam for Stresses of 16 000 and 32 000 Pounds per Square Inch in Lower Fiber

Unit Stress in Lower Layer of Reinforcement 16 000 Pounds per Square Inch

Age, in Weeks	Granite		Gravel		Limestone		Cinders	
	0.5	1.6	0.5	1.6	0.5	1.6	0.5	1.6
4	1270	1775	1300	1760	1030	1500	730	1060
13	1300	1850	1210	1800	1050	1680	800	1240
26	1200	1830	1440	2025	1200	1700	925	1400
52	1420	1980	1470	2225	1120	1950	1050	1475

Unit Stress in Lower Layer of Reinforcement 32 000 Pounds Per Square Inch

4	1850	2520	1850	2630	1480	2030	1040	1550
13	1950	2850	1820	2880	1600	2550	1140	1870
26	1860	3000	1940	3300	1650	2670	1260	2110
52	1950	3250	2110	3500	1630	2950	1410	2300

(d) DISCUSSION OF PHOTOGRAPHS OF BEAMS.

As was described on page 21, the development of the cracks, which were visible on the surface of the concrete, was in a majority of cases traced at intervals throughout the test. At the age of 4 weeks, the development of cracks was traced for each of a set of three identical beams, and this method was also followed in some of the 13-week beams. Since all the beams tested at the age of 4 weeks failed in tension, those at succeeding ages were even more certain to fail in this way, and it was suspected that the change in the beam with age would be insufficient to cause much, if any, change in the time of appearance of the first crack, their development during the test, or their height at maximum load.

In order to save time on tests subsequent to those at the age of 4 weeks, without sacrificing any test data of importance, it was thought best to trace the cracks, at the end of the test, on two beams of a set, and to trace them at various loads throughout the test on the third beam.

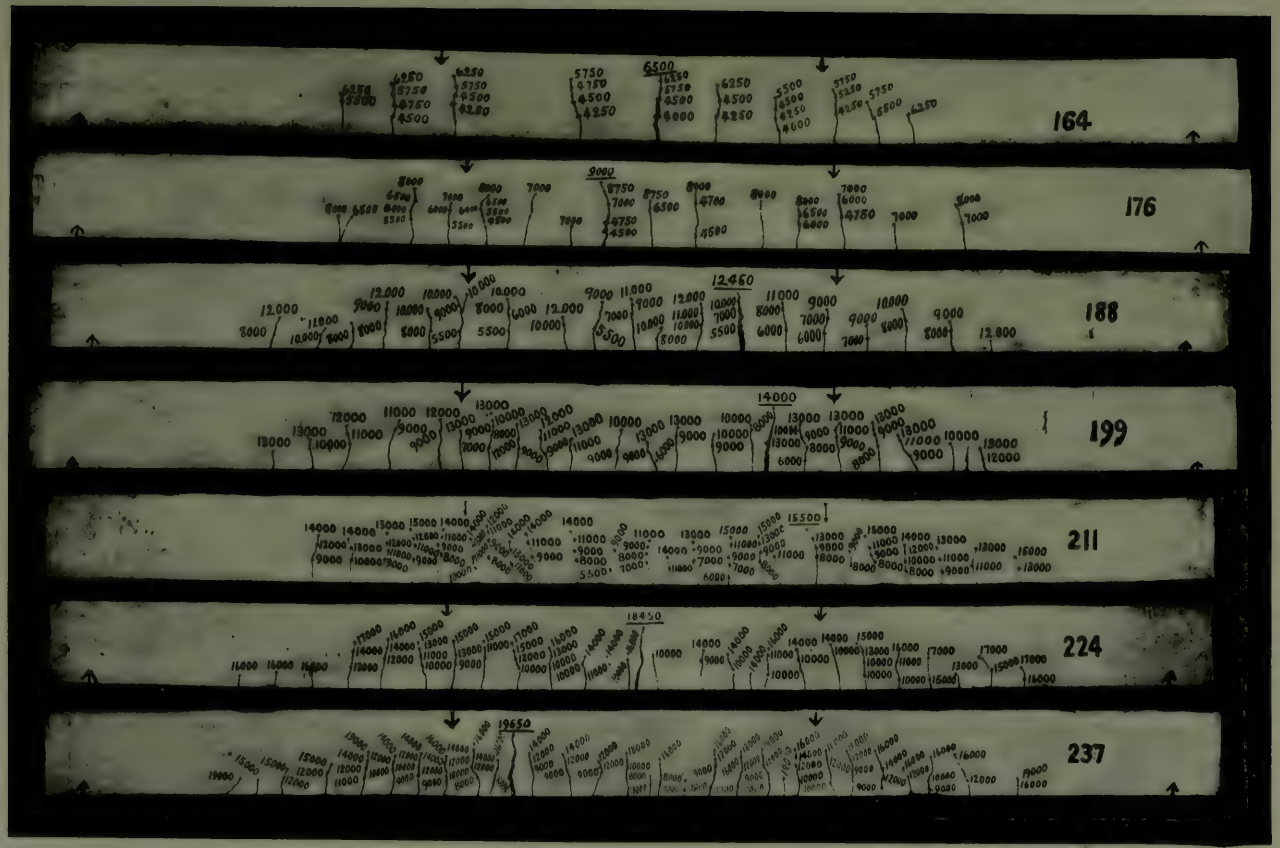

Fig. 22.—*Granite Concrete, Age 4 Weeks, Showing Variation in Position of Cracks with Variation in Percentage of Reinforcement*

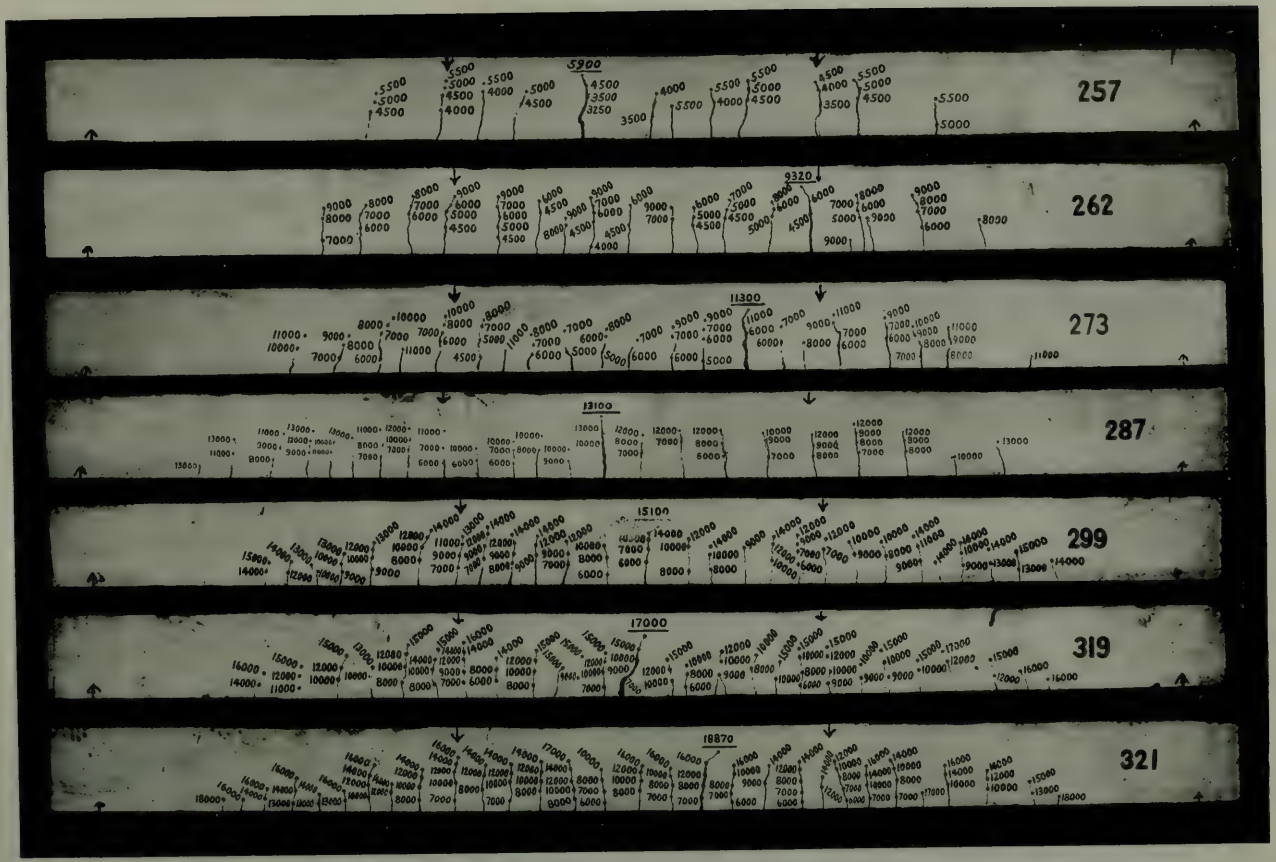

Fig. 23.—*Limestone Concrete, Age 4 Weeks, Showing Variation in Position of Cracks with Variation in Percentage of Reinforcement*

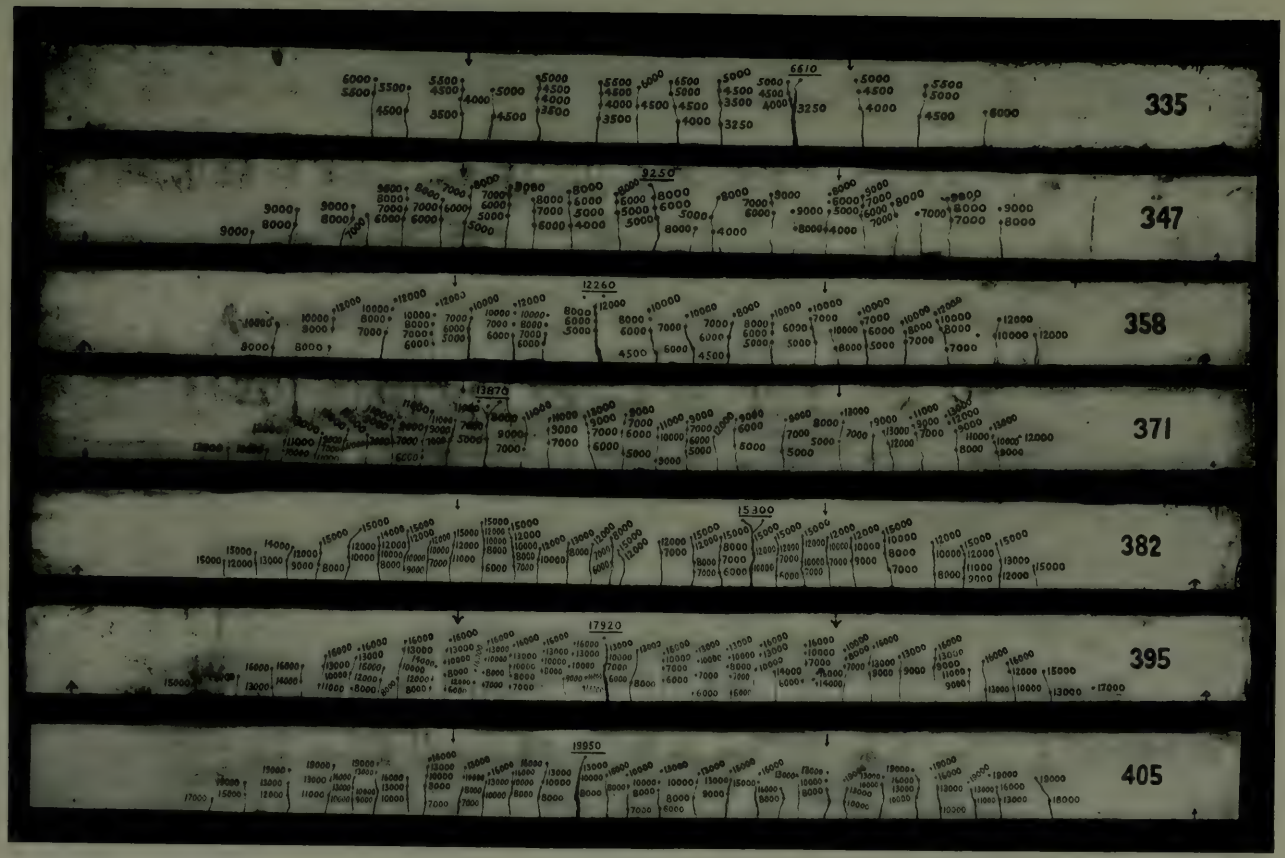

Fig. 24.—*Gravel Concrete, Age 4 Weeks, Showing Variation in Position of Cracks with Variation in Percentage of Reinforcement*

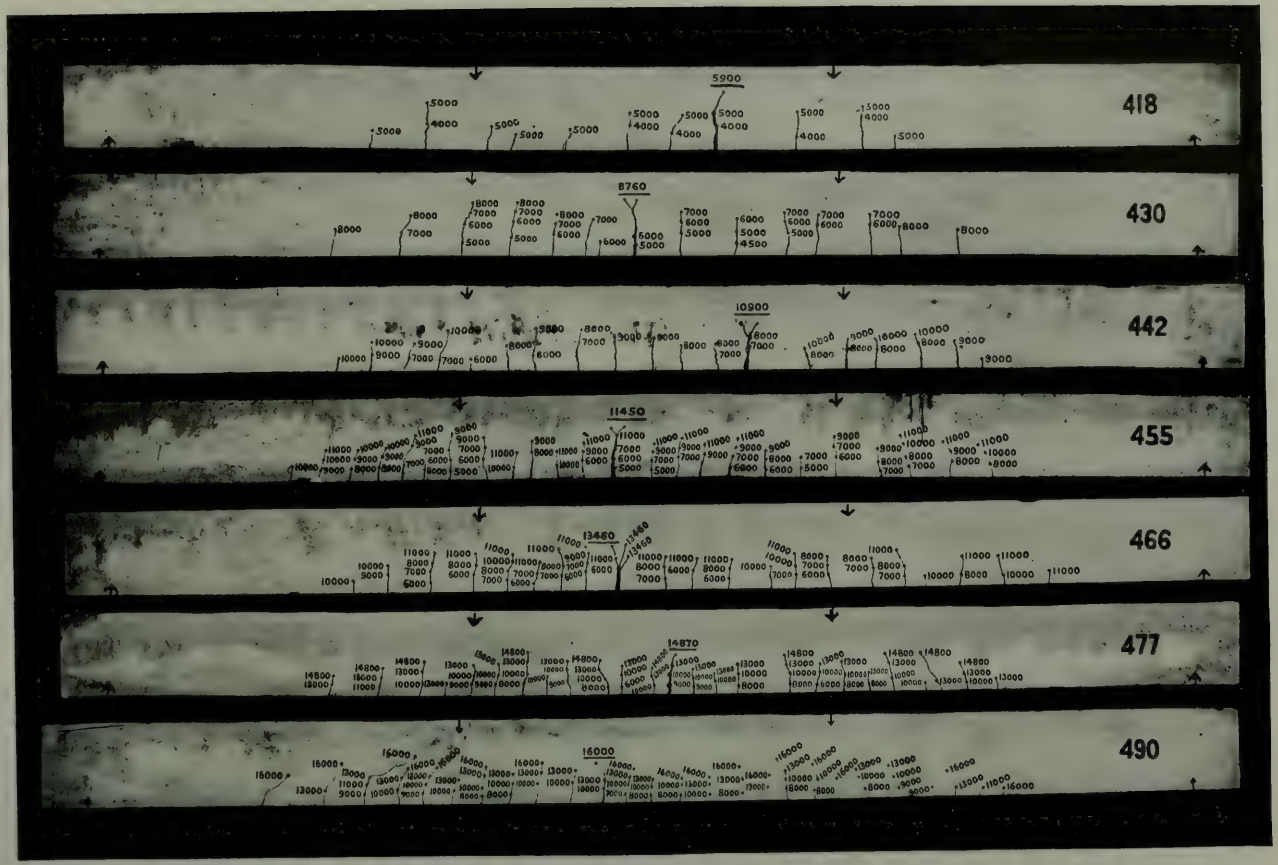

Fig. 25.—*Cinder Concrete, Age 4 Weeks, Showing Variation in Position of Cracks with Variation in Percentage of Reinforcement*

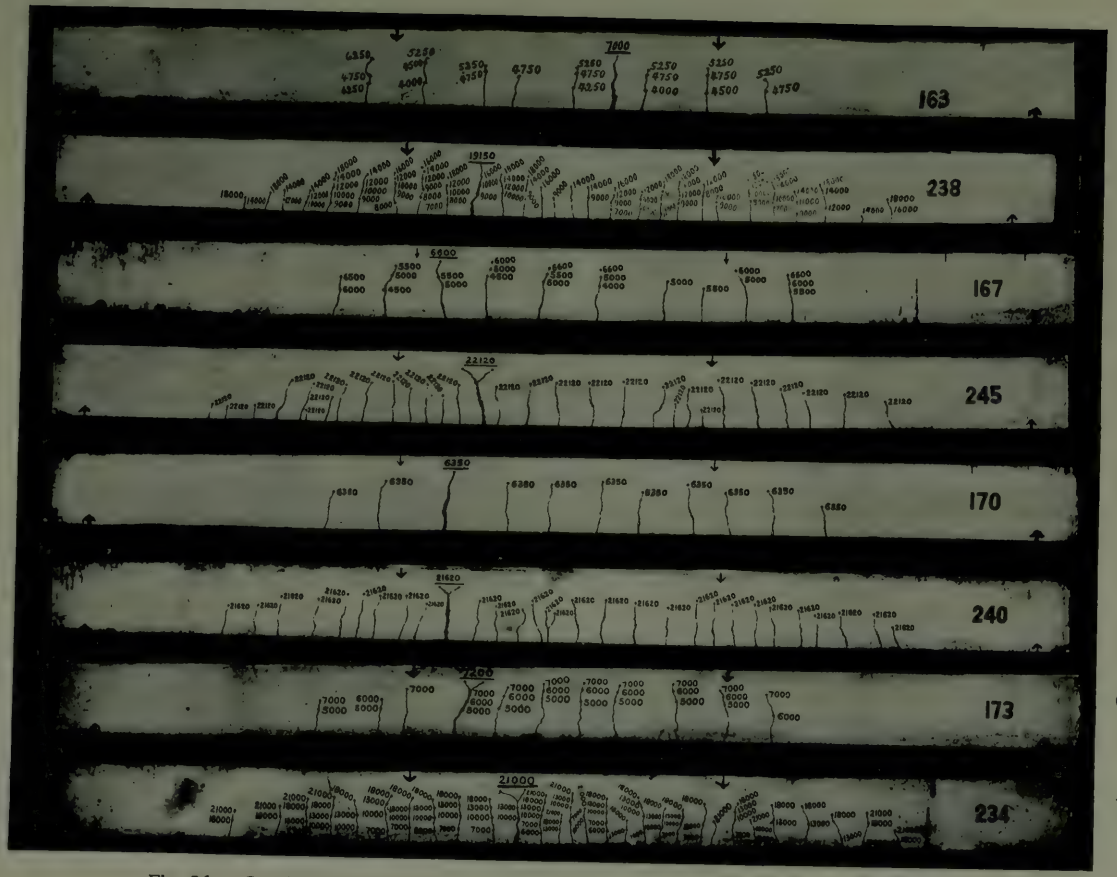

Fig. 26.—*Granite Concrete, Showing Beams with 0.49 and 1.96 Percentages Reinforcement*

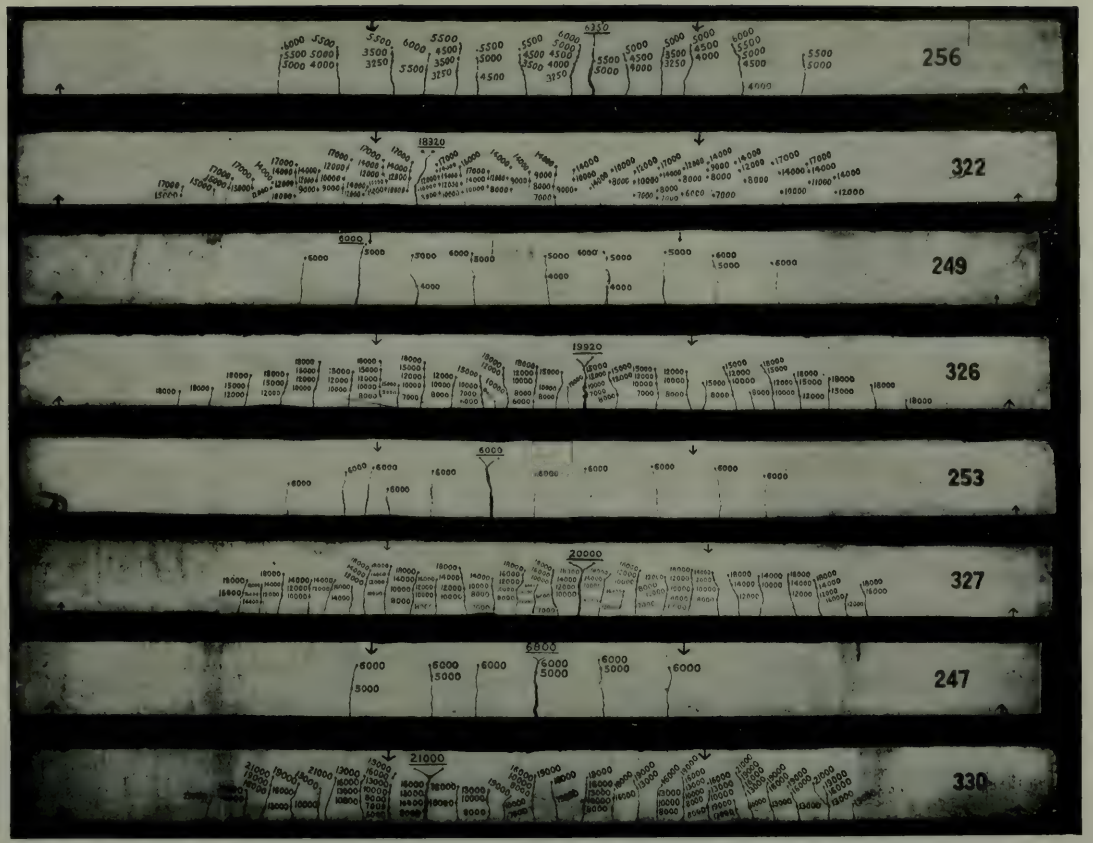

Fig. 27.—*Limestone Concrete, Showing Beams with 0.49 and 1.96 Percentages Reinforcement*

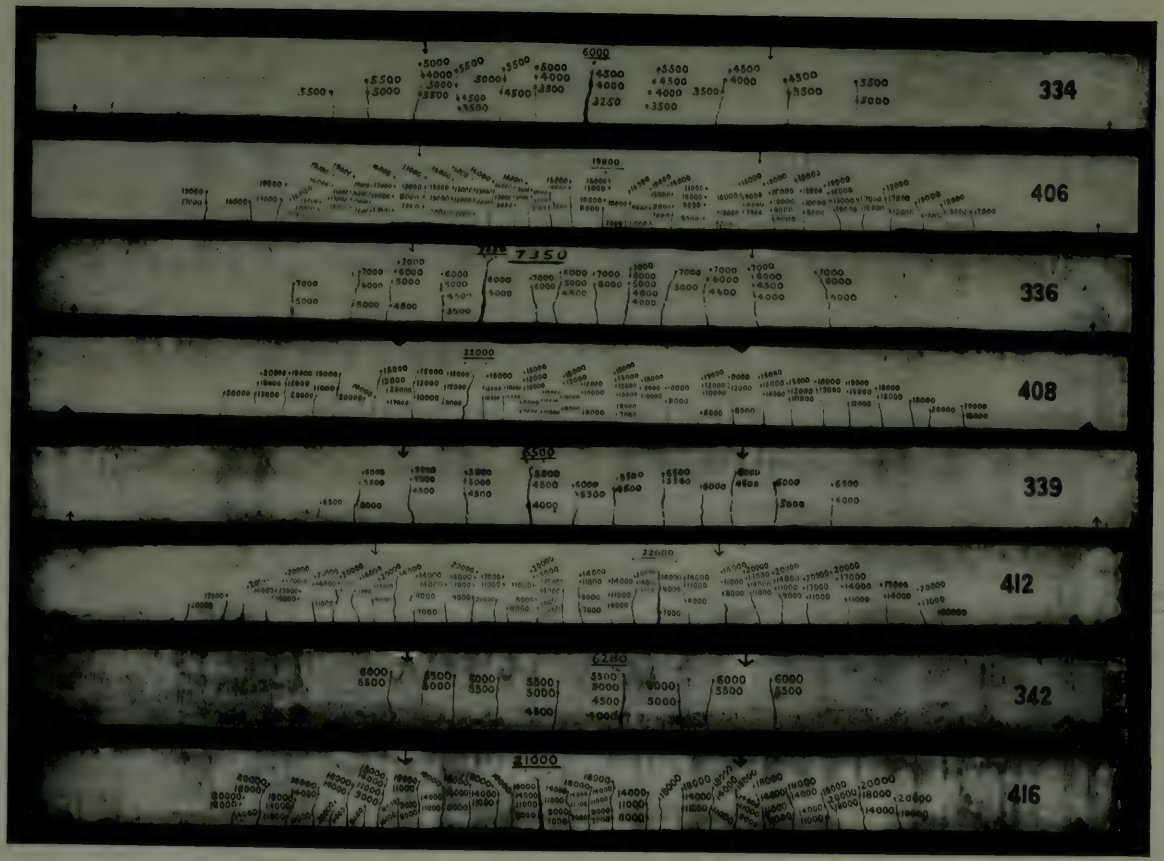

Fig. 28.—*Gravel Concrete, Showing Beams with 0.49 and 1.96 Percentages Reinforcement*

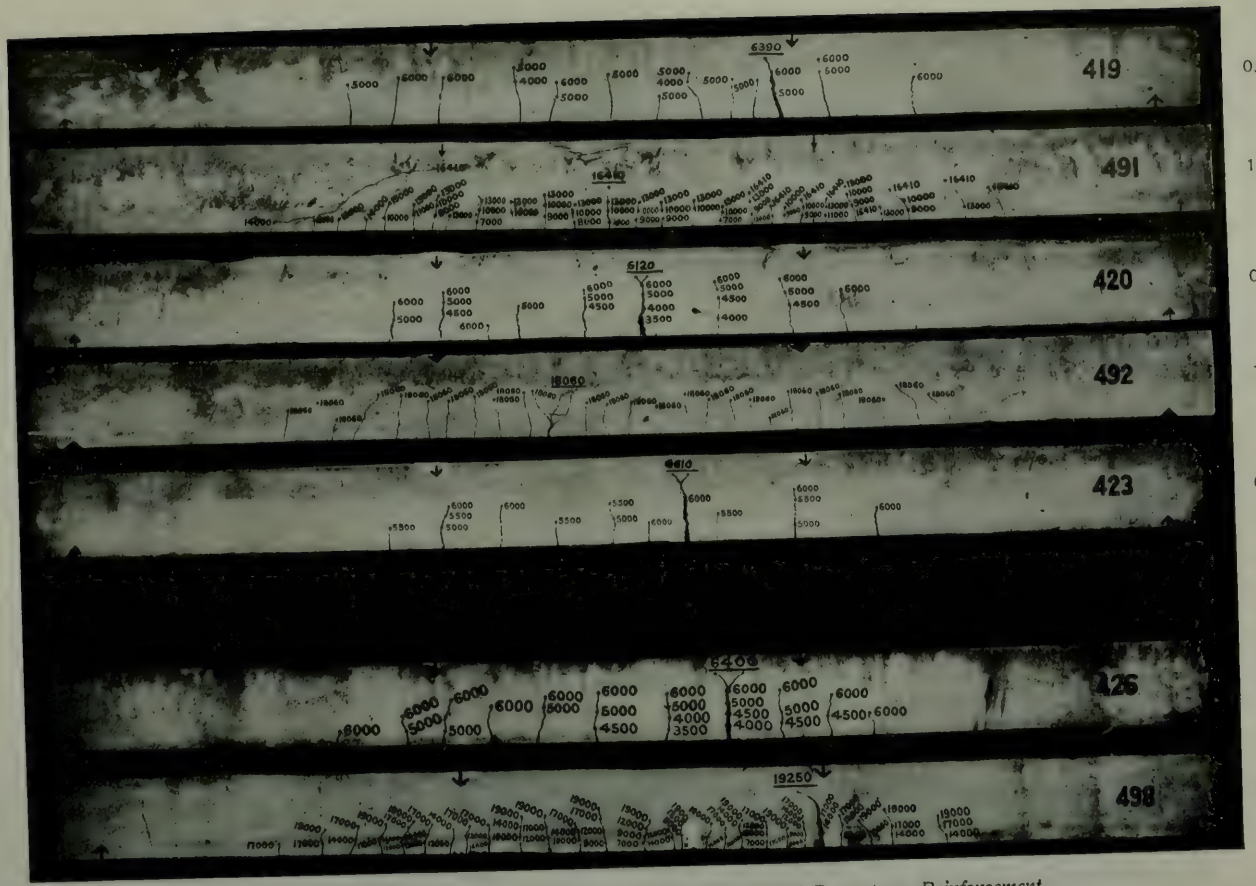

Fig. 29.—*Cinder Concrete, Showing Beams with 0.49 and 1.96 Percentages Reinforcement*

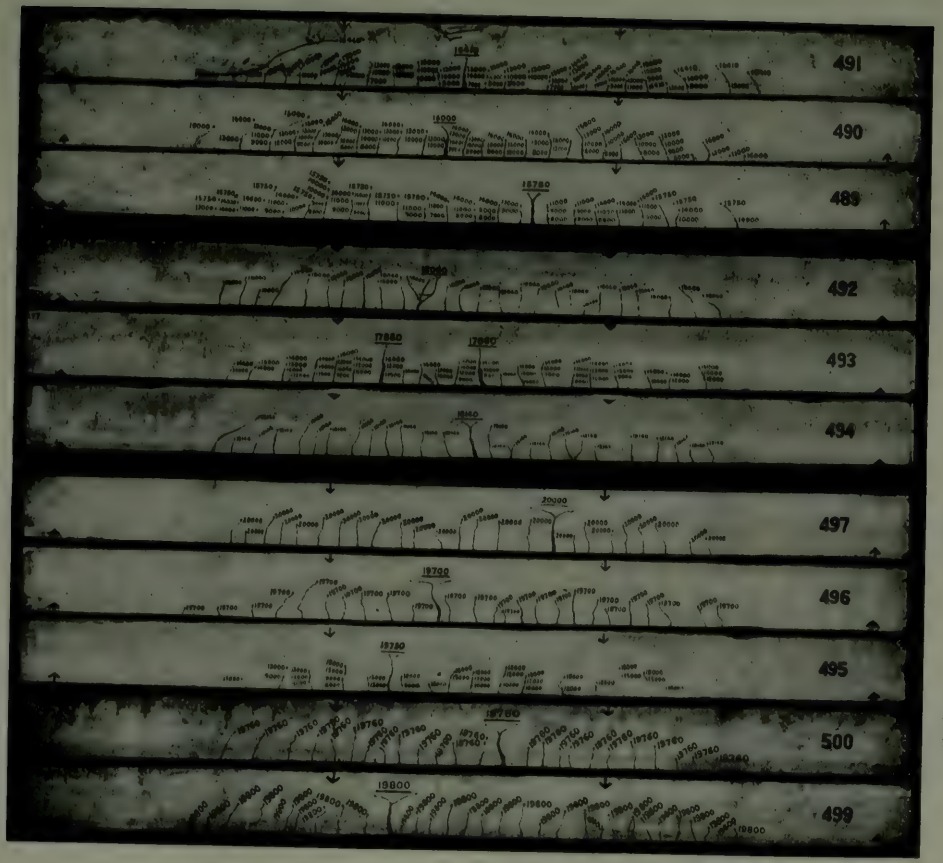

Fig. 30.—*Showing Similarity of Cracking in Similar Beams*

The determination of the loads, at which cracks were traced, was based entirely on the rate at which cracks developed during the test. If the cracks showed an appreciable increase in height, the loads at which cracks were traced were taken closer together, while if their development was slow, the cracks were not traced for every load increment.

With low percentages of reinforcement, cracks developed so rapidly that in many cases the surface was examined after every 500-pound load increment was applied, while with the higher percentages the interval was sometimes as much as 2000 to 3000 pounds.

At that point of the beam at which for a given applied load the crack became invisible the magnitude of the load was marked. After the test was completed the cracks were outlined and the applied loads indicated with black paint showing the height of the crack during different stages of the test. The three identical beams for a given age were then piled one on top of another and the group photographed.

Representative photographs have been reproduced in Figs. 22 to 30.

An examination of these photographs will bring out the following facts:

1. The spacing of the cracks is independent of the kind of aggregate and the age of the concrete.

2. The spacing varies with the percentage of reinforcement, being about 7 inches for 0.5 per cent nominal reinforcement for all aggregates, and varies from about 3 inches for stone aggregates to 3½ inches for cinders with 2 per cent nominal reinforcement.

3. While the difference is in all cases slight, the cracks seem to extend up higher with stone and gravel concrete than with cinder concrete. The cracks as a rule are approximately vertical, with the exception of those outside the load points, for a high percentage of reinforcement and with cinder concrete.

4. The fact that the first visible crack occurs at higher loads, as the percentage of reinforcement is increased, may be due either to the lowering of the neutral axis, as influencing the height of the cracks, or upon the larger number of cracks in a given length of beam, which for the same total deformation must cause the indi-

vidual cracks to be smaller than is the case for lower percentages of reinforcement.

5. For a nominal reinforcement of 0.5 per cent the applied load at first *visible* cracks varies from 3250 to 4000 pounds at the age of 4 weeks to 4000 to 5000 pounds at 52 weeks while with 2 per cent it varies from 6000 to 7000 pounds at 4 weeks.

2. COMPRESSION TESTS

While a large number of cylinders and cubes (333 of each) were tested and it was necessary to draw stress deformation curves for each cylinder in order to obtain the moduli and yield point which are reported in Tables 33 to 36, it was not deemed essential to reproduce them in this paper and only one log sheet is reproduced for each aggregate and age.

For the stone and gravel concrete there is little difference between the proportions by weight and by volume. This is due to the fact that the weight per cubic foot of the sand and of the stone differs but little from 100 pounds. The proportions by weight for the cinder concrete differs considerably from the proportions by volume, due to the low weight per cubic foot of the cinders.

The percentage of water given is obtained in the same way as already described (p. 18) and brings the concrete to medium consistency as there defined. The percentage of water required for the granite is about 8.3; limestone 10; gravel 9.5; and about 18.9 for the cinders.

The weight per cubic foot of the concrete as given in column 5, Tables 33–36, varies from about 148 to 149 pounds for granite, about 146 to 147 pounds for limestone, 143 to 144 pounds for gravel and 118 to 119 pounds for cinders. The weight per cubic foot of the 6-inch cubes as given in column 11 is much more erratic than that obtained for the cylinders although the average is not so very different. The stone and gravel concrete is seen to differ but little from 150 pounds per cubic foot, the weight usually assumed.

Column 5 contains the ultimate strength of the cylinders, while column 10 contains the ultimate strength of the cubes.

Two hundred thousand pounds was the capacity of the largest machine available at the time the 4, 13 and 26 week tests were made. The sectional area of an 8-inch cylinder is approximately

50 square inches, while a 6-inch cube is 36 square inches. Consequently all cylinders which would go above 4000 pounds per square inch, and all cubes stronger than about 5500 pounds per square inch could not be broken. This was the case with the 13 and 26 week granite cylinders and a few of the cubes, several of the 13 and 26 week limestone cylinders and all but one of the 13 and 26 week gravel cylinders. The quantity followed by an asterisk, in the columns for ultimate strengths, are not to be understood as being the ultimate compressive strength of the concrete but are obtained by dividing 200 000 pounds the capacity of the machine, by the actual sectional area of the test piece. It is thought, however, that the ultimate strength of the granite and gravel cylinders at 13 weeks differs but little from the values given in this table, as will be indicated later.

The average line of the last column of these tables contains the ratio of the ultimate strength of the cylinders to that of the cubes. Where both the cylinders and cubes broke, this ratio could be obtained directly from the data and is correct. For those cases in which the ultimate strength of all the cylinders in a given group exceeded the capacity of the machine, this ratio could not be obtained directly and the following method was used and is believed to give results which approximate the true values. These approximate values are shown diagramatically in Figs. 31 and 32.

This method assumes that the quality of the concrete is the same in both cylinders and cubes and that therefore their ultimate strength for a given age is a function of their shape alone. If this is true, the ratio of the ultimate strength of the cylinders of two different aggregates should be the same as the ratio of the ultimate strengths of the cubes of the same aggregate.

This would mean that if we started with the known ratio of the ultimate strengths of the cubes, and multiplied by the ultimate strength of the cylinders that did break, the resulting product should be the ultimate strength of the cylinders that did not break. This is, of course, only an approximation and the result is necessarily in error, but the degree of accuracy may be judged by the uniformity with which the points thus obtained line up with those at 4 and 52 weeks, at which ages all the test pieces were broken,

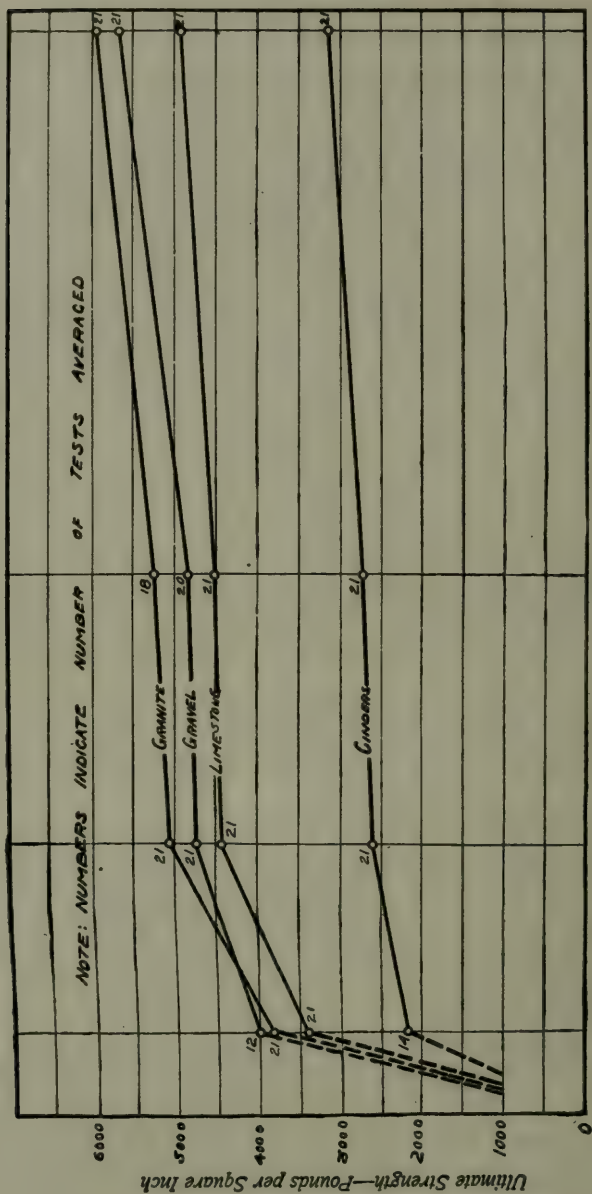

Fig. 31.—*Effect of Age on Compressive Strength of Six-Inch Cubes. (Age in Weeks)*

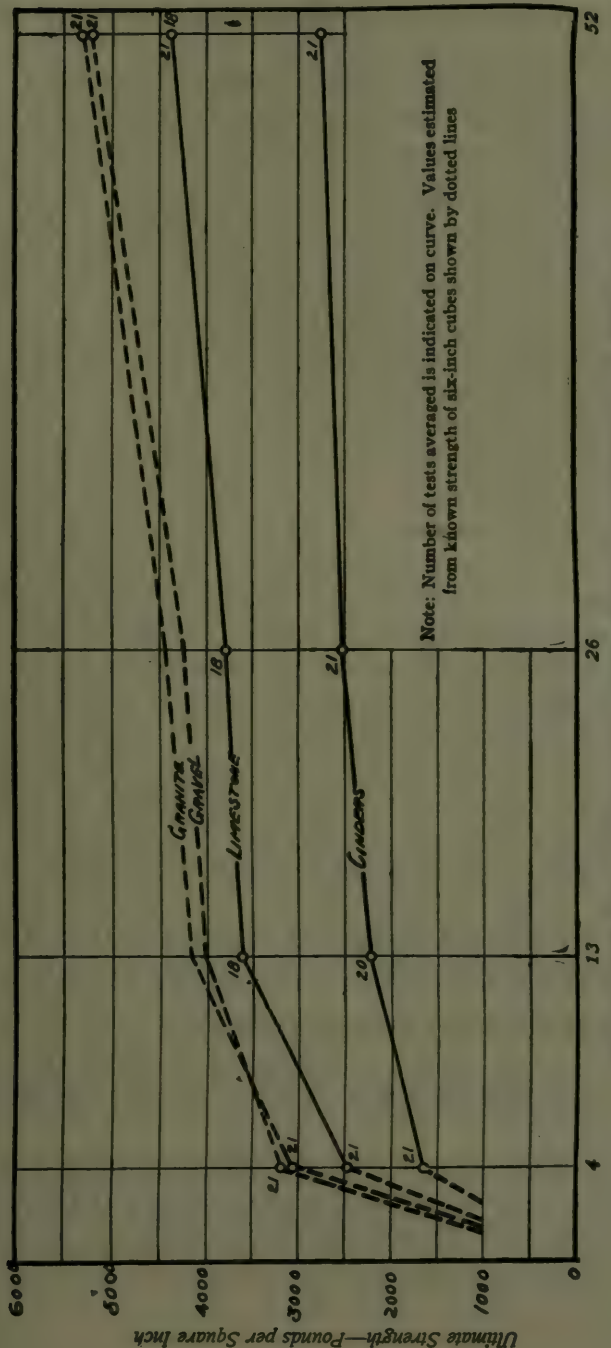

Fig. 32.—*Effect of Age on Compressive Strength of Eight-Inch Cylinders. (Age in Weeks)*

and also by the fact that the ultimate strength could not be below 4000 pounds per square inch.

Column 7 contains the initial modulus of elasticity. These values were obtained by drawing a line, as already indicated, on the individual compression-stress gross-deformation curves obtained by plotting the data as given on page 140. The average of these values gives the average modulus of elasticity obtained by drawing a line on the compressive-stress gross-deformation curve constructed with the average unit gross deformation and the average unit compressive stresses for each age and aggregate.

Column 8 contains the yield point and was obtained from the individual curves as indicated.

The data summarized in these tables will enable a comparison to be made between individual values and will serve as a check on the uniformity of the tests. For the comparison of the different materials and the influence of age on the strength and elastic behavior of the concrete, average values can be used to greater advantage and lead to conclusions of more general application. Any investigation of concrete in compression should furnish data showing the influence of age on the strength and elasticity of concrete and the relative strengths of concrete of different aggregates. The following comparisons are made on the tests herein reported:

(*a*) Influence of age on the ultimate strength of cubes and cylinders.

(*b*) Effect of age on the initial modulus of elasticity.

(*c*) Effect of age on yield point.

(*d*) Ratio of ultimate strength of cylinders to that of cubes.

(*e*) Ratio of the yield point to the ultimate strength.

(*a*) INFLUENCE OF AGE ON THE ULTIMATE STRENGTH OF CUBES AND CYLINDERS

Fig. 31, page 100, shows the influence of age on the ultimate strength of the cubes while Fig. 32 gives the same information for the cylinders.

Examining Figs. 31 and 32 the growth in strength of cinder concrete from 4 to 13 weeks is seen to be 19.4 per cent for the cubes, 34.7 per cent for the cylinders; from 4 to 26 weeks the increase is about 25.5 per cent for the cubes to 53.4 per cent for

the cylinders, while the cylinders increase 9.4 per cent from 26 to 52 weeks, and the cubes 15 per cent.

Similarly, limestone shows an increase from 4 to 13 weeks of 30 per cent for the cubes, and for the cylinders 44.5 per cent, while from 4 to 26 weeks the increase is 32.8 and 52 per cent, respectively. From 26 to 52 weeks the gain for the cylinders is 16 and for the cubes 9.8 per cent.

The granite cubes show an increase of 32.5 per cent from 4 to 13 weeks and 37.6 per cent from 4 to 26 weeks. The increase in the strength of the cylinders can not be determined exactly. Their ultimate strength at the age of 4 weeks was 3054 pounds, while at 13 and 26 weeks it exceeded 4000 pounds per square inch, the capacity of the testing machines. At 52 weeks the increase in the strength of the cylinders over that at 4 weeks was 73.4 per cent.

The gravel cubes showed an increase of 18.3 per cent from 4 to 13 weeks and 2.1 per cent from 13 to 26 weeks. The gravel cylinders at 4 weeks had an ultimate strength of 3175 pounds, and, as was the case for the granite, exceeded 4000 pounds at succeeding ages. The increase in strength at 52 weeks over that at 4 weeks was 65 per cent. What seems particularly noticeable in the above tests is the substantial and uniform increase in strength up to an age of 1 year, at which time it is still gaining strength. In general, it may be roughly stated that the concrete used in these tests increased 65 per cent in strength from an age of 4 weeks to that at the end of a year and that at that time was still increasing in strength.

(b) EFFECT OF AGE ON THE INITIAL MODULUS OF ELASTICITY

The influence of age on the initial modulus of elasticity is shown graphically in Fig. 33, page 105. The points plotted are the averages of the values in Tables 33 to 36.

An examination of this figure will show that the modulus of elasticity does vary with age as does the ultimate strength. Granite shows the smallest increase, the modulus at 26 weeks being but 5 per cent greater than that at 4 weeks, while cinders with the least ultimate strength show an increase of 32 per cent for the same ages and just about half as much at 13 weeks. Gravel

shows scarcely any increase from 4 to 13 weeks, but a substantial increase of 14 per cent from 4 to 26 weeks, while for limestone there is an increase of 6 per cent from 4 to 13 weeks and a 20 per cent increase at 26 weeks over the results at 4 weeks.

The actual values are in all cases, except the cinder concrete, fairly high and while it should be remembered that the concrete did not rest for any length of time under load before the micrometers were read (about one minute per 100 pounds per square inch), yet the moduli are not as high as would be the case if based on elastic rather than gross deformations.

(c) EFFECT OF AGE ON YIELD POINT

It has already been indicated that for stresses below the yield point the gross deformation curve for concrete in compression is sensibly a straight line. Even beyond this point many curves follow this line for a considerable distance, so that a constant modulus of elasticity can be assumed for these concretes up to a unit stress considerably in excess of the yield point. The following table shows the percentage variation of the average curves, Figs. 37, 38, 39 and 40, pages 111 to 114, from the straight line for an assumed unit stress 1.5 times the yield point.

Table 37.—Variation of the Average Deformation Curve for a Load 1.5 Times Yield Point

Age, in Weeks	Cinders		Granite		Gravel		Limestone	
	Load, lbs. per sq. in.	Variation, per cent.	Load, lbs. per sq. in.	Variation, per cent	Load, lbs. per sq. in.	Variation, per cent	Load, lbs. per sq. in.	Variation, per cent
4	750	4.5	1350	5.3	1500	5.2	1050	5.3
13	750	4.5	1950	3.1	2250	3.1	2100	5.0
26	1350	5.2	1650	2.1	1800	3.0	1500	4.2
52	1350	3.7	2700	4.4	2250	3.2	2400	6.5
Average	....	4.0	....	3.7	....	3.6	....	5.4

An examination of the above percentages shows that, even for such high unit stresses, the percentage variation from a straight line is relatively small.

The variation with age, of the average yield point, as given in Tables 33 to 36, pages 129 to 136, is shown in Fig. 34, page 106. In

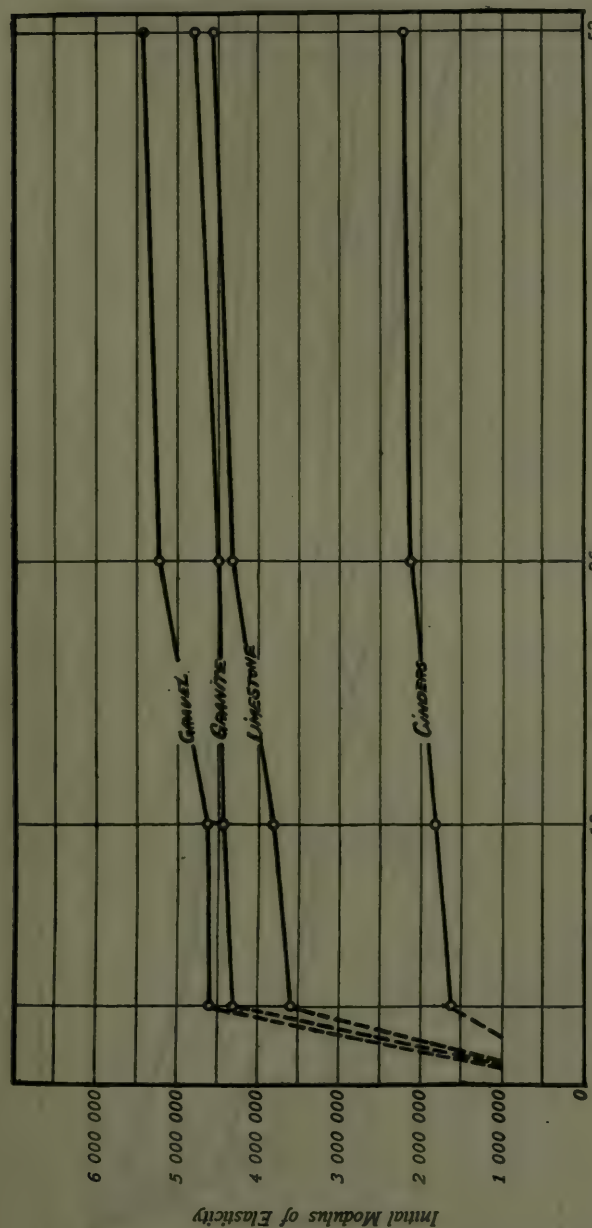

Fig. 33.—*Effect of Age on the Initial Modules of Elasticity of Concrete in Compression.* (*Age in Weeks*)

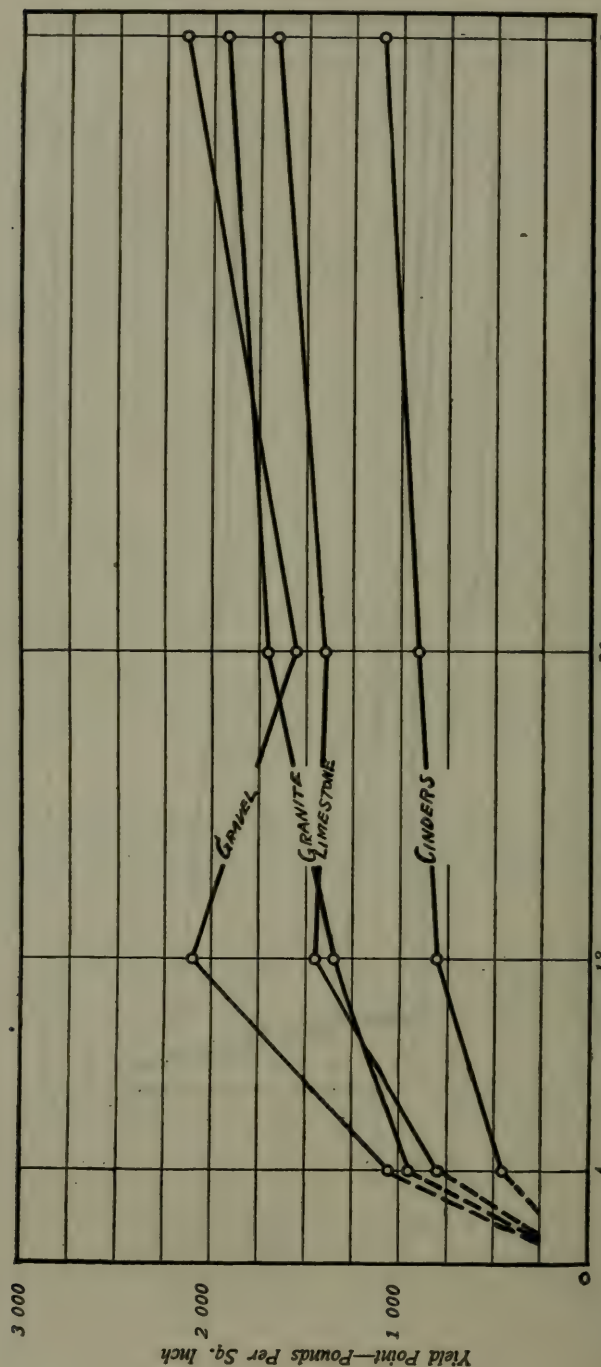

Fig. 34.—*Effect of Age on the Yield Point of Concrete in Compression.* (*Age in Weeks*)

every case the yield point increases from 4 to 13 weeks and for the granite and cinder continues to increase up to 52 weeks. Although the modulus of elasticity of the gravel and limestone increases from 13 to 26 weeks, the yield point seems to decrease, indicating that while the initial part of the curve at 26 weeks is steeper than at 13 weeks yet it turns from the straight line at a lower unit stress. While no explanation of this behavior is suggested, the peculiarity is similarly illustrated in Figs. 37 to 40, pages 111 to 114. At the age of 52 weeks the yield point for these aggregates again show an increase.

As may be seen from Fig. 36 in only one instance, namely, the four-week tests on cinder concrete, does the range fall below 500 pounds per square inch. It would seem, therefore, that the assumption of a straight-line stress gross-deformation diagram for concrete in compression is permissible for all average concretes of the proportions and ages given and is certainly warranted for all the stone and gravel concretes herein reported. As will be shown in discussing the results of the tests on the reinforced beams, the fact that the concrete in many of the beams is stressed considerably above this point seems to exert little influence on the position of the neutral axis and consequently upon the resisting moment of all beams failing by the tension of the reinforcement, although it does determine the stress in the extreme fiber of the concrete.

(*d*) RATIO OF THE ULTIMATE STRENGTH OF THE CYLINDERS TO THE ULTIMATE STRENGTH OF THE CUBES

The ratio of the ultimate strength of the cylinders to that of the cubes is shown graphically in Fig. 35, page 108. The number of tests which were averaged for the point plotted is indicated by a number at each point. Where a different number of tests were averaged for both the cylinders and cubes, the numbers are written as a fraction—i. e., $\frac{21}{14}$. This would indicate that the ratio as plotted was obtained by dividing the average ultimate strength of 21 cylinders by that of 14 cubes.

It was explained on pages 99 and 100 that in a number of cases the ultimate load of the cylinders exceeded the capacity of the testing machine and that an attempt was made to approximate their ultimate strengths. These approximate ultimate strengths were used

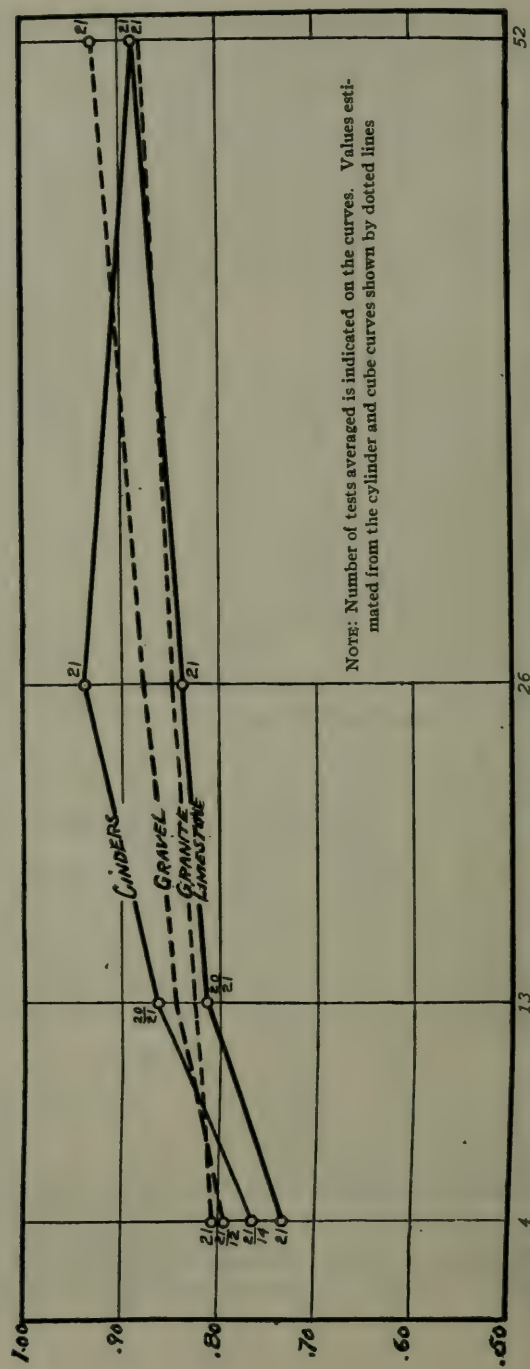

Fig. 35.—*Effect of Age on the Ratio of the Ultimate Strength of Cylinders and Cubes.* (*Age in Weeks.*)

in obtaining the ratios for the points that are connected by dash lines on the diagram.

In every case the ratio increases considerably with age, the ultimate strength of the cylinder approaching that of the cubes at the age of 52 weeks.

(e) RATIO OF THE YIELD POINT TO THE ULTIMATE STRENGTH

Fig. 36, page 110, shows the ratio of the yield point to the ultimate strength for different ages, computed on approximate ultimate strengths as described on page 107. The erratic value for gravel concrete at the age of 13 weeks is due to the high value of the yield point as given in Fig. 36. The ultimate strength, Fig. 32, of the gravel at the age of 13 weeks compares favorably with that at 4 and 26 weeks, and with the strength of the other concretes, and there is no apparent reason why at this age such a high value should be obtained for the yield point.

Fig. 36 shows that the ratio of the yield point to the ultimate strength increases approximately between 4 and 52 weeks, from 0.30 to 0.40.

(f) AVERAGE STRESS-GROSS DEFORMATION CURVES

Since general relations can be brought out much more clearly by the comparison of average curves than by the inspection of a large number of individual curves, Figs. 37, 38, 39, and 40 were prepared. In each case the average unit stress of the cylinders is plotted against the corresponding average unit gross deformation.

The values plotted, which are the averages for 21 cylinders for each age and aggregate, were obtained from the log sheets for the individual cylinders. Since there is considerable difference in the ultimate strength of supposedly identical test pieces, the compressometer for measuring the compression was necessarily removed from some test pieces earlier than others. Since the upper limit of the curve is determined by the lowest unit stress at which the compressometer is removed in a given set of 21 cylinders, the last point in several cases is considerably below the average ultimate strength. In several cases points, which are the averages of less than 21 tests, have been plotted, but in many cases after several test pieces have dropped out, the curve beyond this point does not line up with that below. In every case the curve

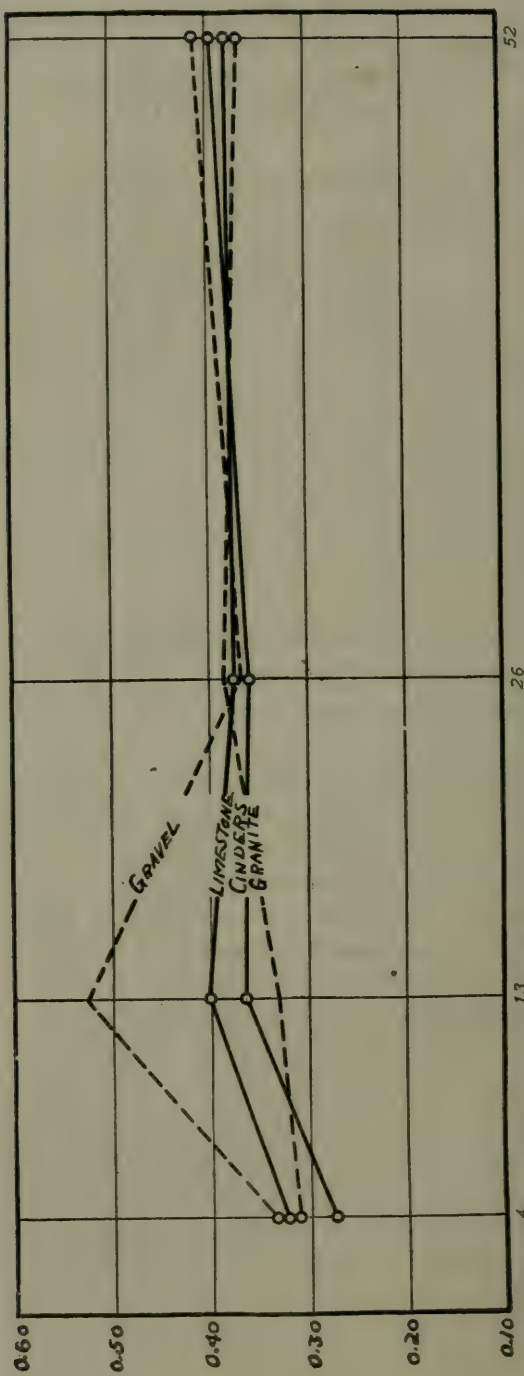

Fig. 36.—*Effect of Age on the Ratio of the Yield Point in Pounds per Square Inch to the Ultimate Strength. (Age in Weeks)*

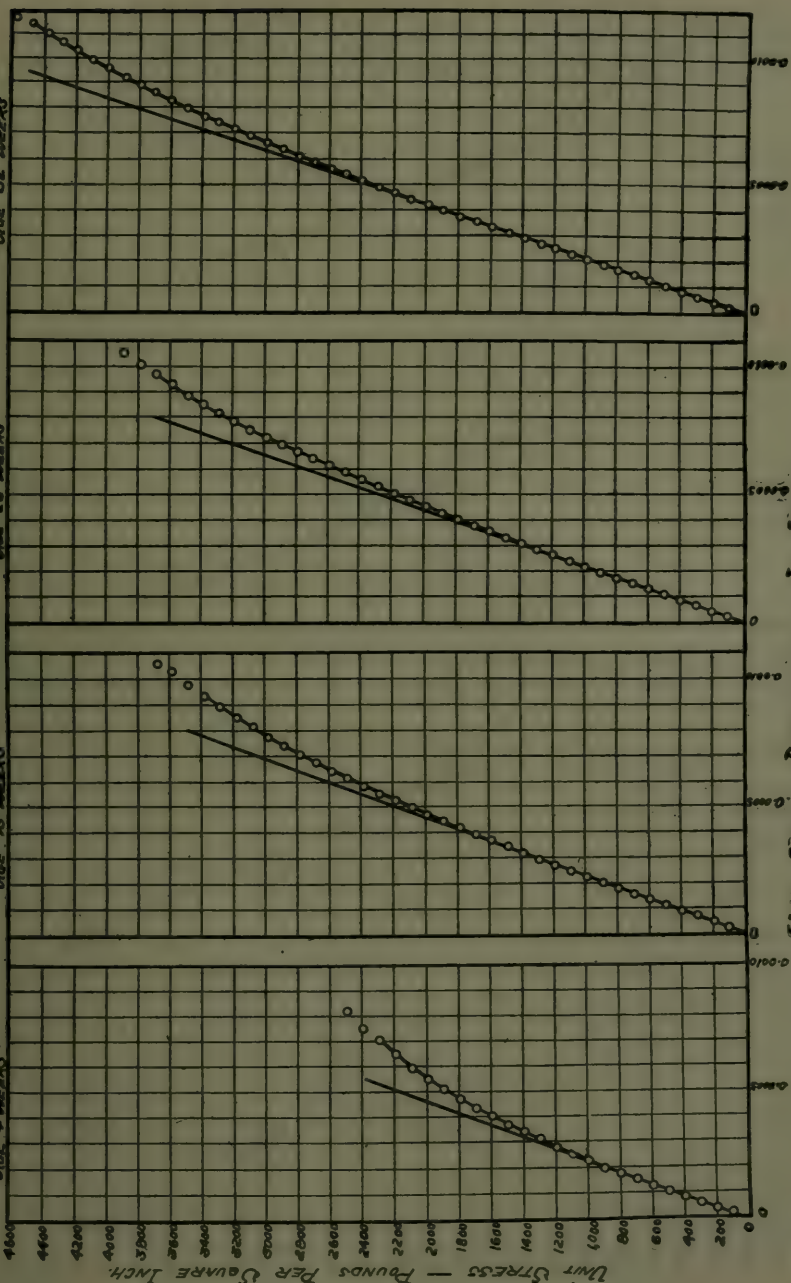

Fig. 37.—*Average Compressive Stress Gross Deformation Curve for Granite Concrete*

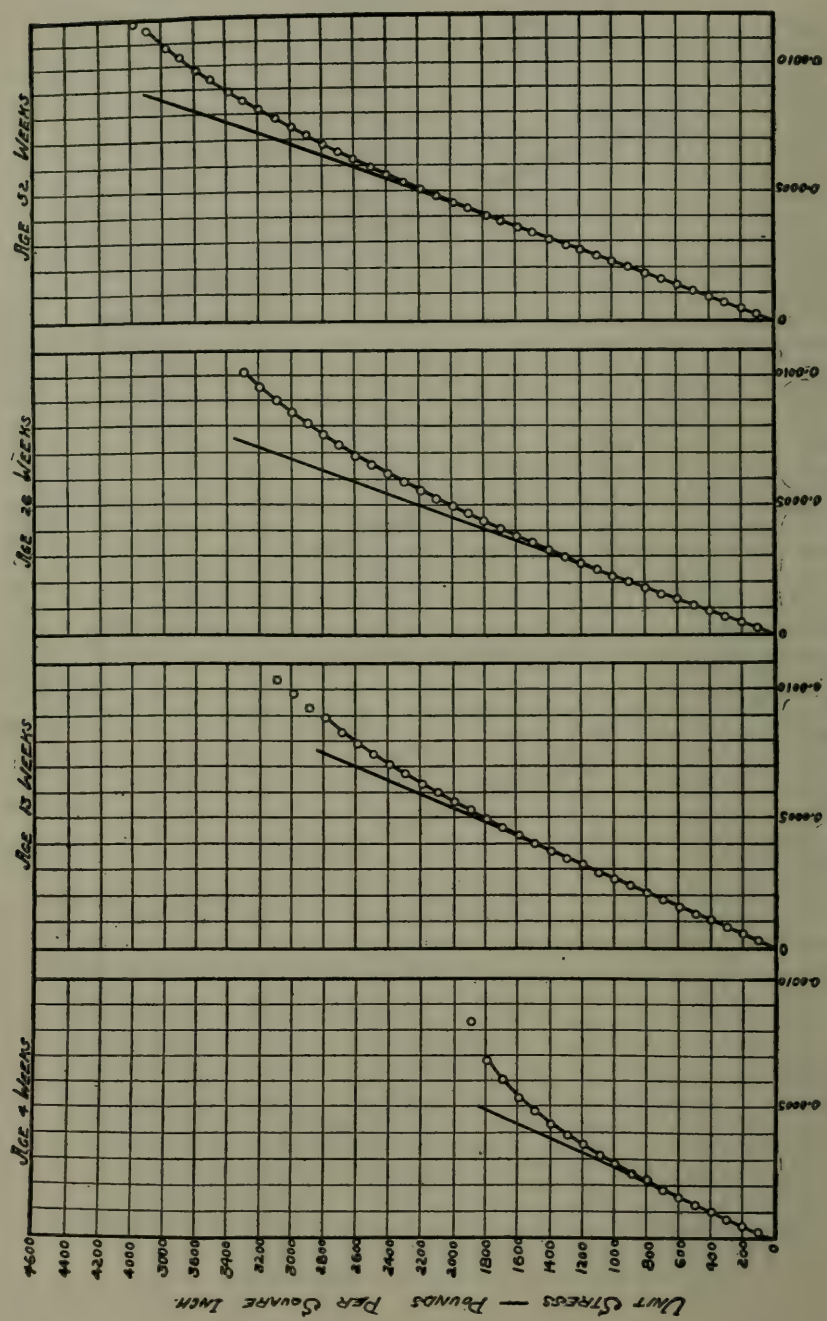

Fig. 38.—Average Compressive Stress Gross Deformation Curves for Limestone Concrete

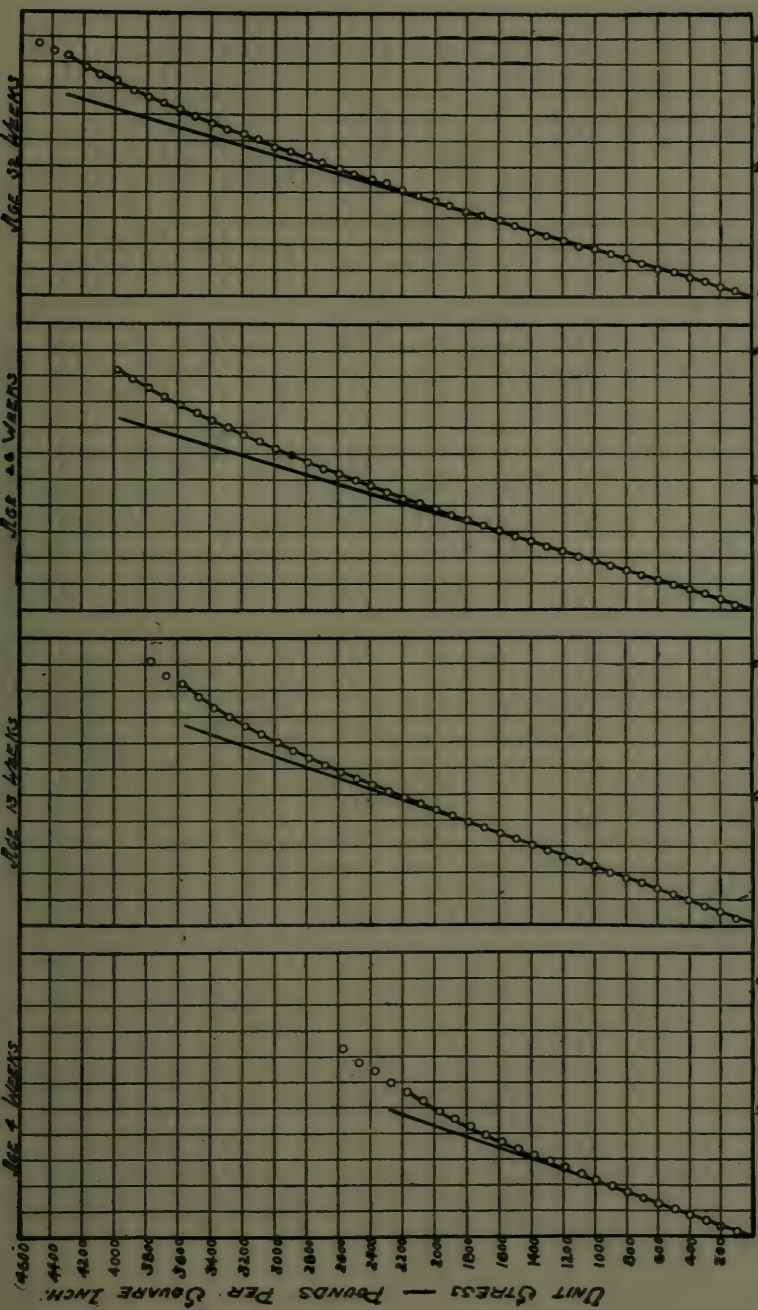

Fig. 39.—Average Compressive Stress Gross Deformation Curves for Gravel Concrete

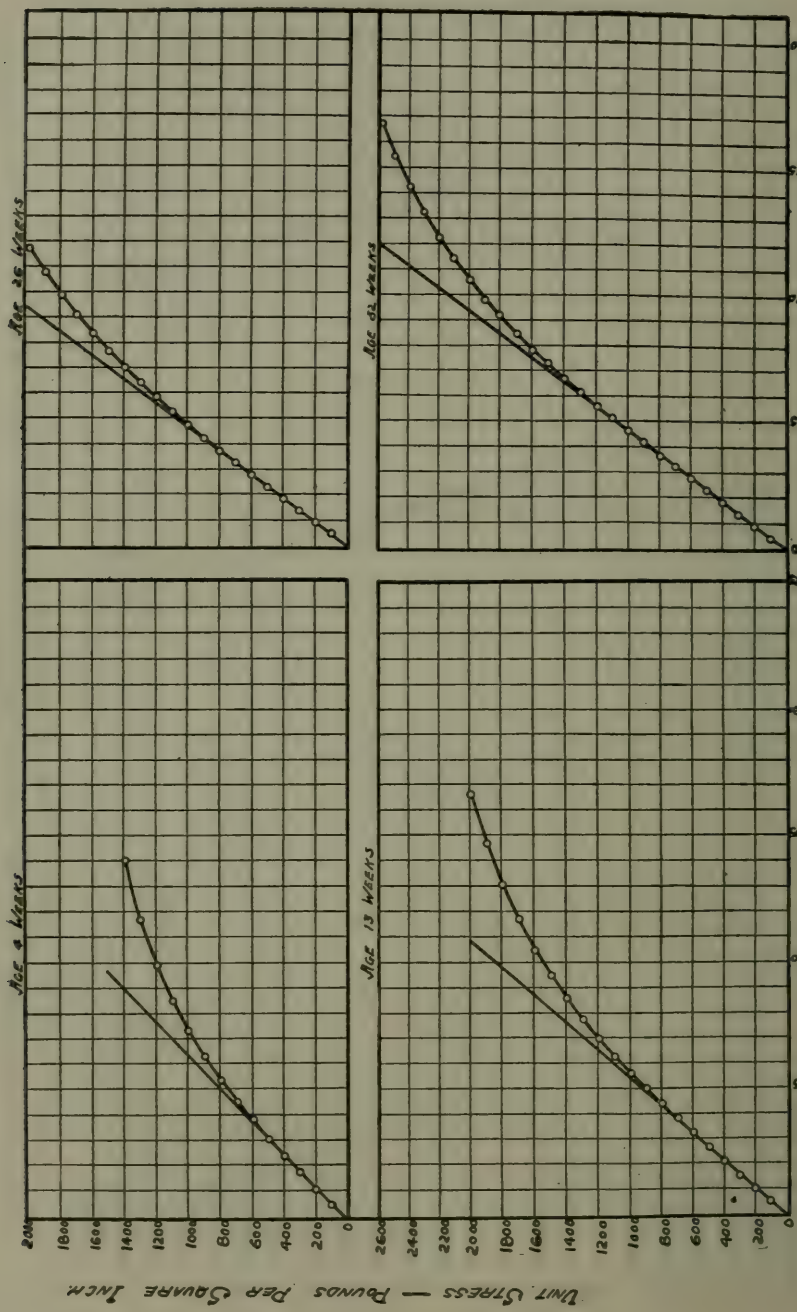

Fig. 40.—Average Compressive Stress Gross Deformation Curves for Cinder Concrete

itself has been drawn up to the last point only for which 21 tests have been averaged. The values from the log sheet of one representative cylinder for each age and aggregate are given in Appendix I.

The increase in slope of the line of initial coefficient of elasticity with age is very clearly brought out by these figures, and it is believed that they show very representative curves for the aggregates used.

VII. CONCLUSIONS

1. REINFORCED CONCRETE IN FLEXURE

From a study of the behavior of the reinforced concrete beams herein reported the following conclusions may be stated:

(a) CONDITIONS AT FIRST CRACK

(1) The unit elongation of the extreme lower fiber at the time of the occurrence of the first crack is 0.00012, for stone and gravel concrete, 0.00018 for cinder concrete, and equals the unit elongation of the lower fiber at rupture of a beam of the same concrete without reinforcement.

(2) The unit elongation of the extreme lower fiber at time of the occurrence of the first visible crack increases with the percentage of reinforcement.

(3) The distance between cracks due to tension varies with the percentage of the reinforcement, slightly with the kind of aggregate, and is independent of the age of the concrete.

(b) STRESS IN REINFORCEMENT AT MAXIMUM LOAD

(1) The ratio of the unit stress in the reinforcement at maximum load to the yield point varies with the percentage of the reinforcement, is independent of the age of the concrete, and shows no regular variation with the initial modulus of elasticity of the concrete.

(c) BOND STRESS IN REINFORCEMENT

(1) The unit bond stress at a load just below maximum, for a unit stress in the reinforcement somewhat less than the yield point, is almost constant and equal to about 120 pounds per square inch.

It increases slightly as the percentage of the reinforcement increases, increases somewhat with age, and with the strength of the concrete.

(*d*) RESISTING AND BENDING MOMENT

(1) Basing the resisting moment of a reinforced concrete beam on the tensile stress in the reinforcement, and neglecting the tensile resistance of the concrete, the ratio of the resisting moment to the bending moment is always less than 1 between 0.5 per cent and 1.7 per cent "effective" reinforcement. This ratio is independent of the kind of aggregate used, decreases with age, and increases with the percentage of reinforcement.

(*e*) EFFECTIVE PERCENTAGE OF REINFORCEMENT

(1) The behavior of a reinforced concrete beam, having the reinforcement in two horizontal planes is identical with a beam having all the reinforcement concentrated in one plane, and equal in amount to the reinforcement in the lower plane plus that in the upper plane multiplied by the ratio of the distances of the upper and lower planes from the neutral axis.

(*f*) VARIATION OF THE POSITION OF THE NEUTRAL AXIS

(1) **With effective percentage of reinforcement.**—The percentage depth of the neutral axis below the top of the beam increases with the percentage of reinforcement and increases or decreases with different amounts of reinforcement as the intensity of loading increases, depending upon the ultimate strength of the concrete as influencing a compression failure, and the relative stiffness of the concrete for varying degrees of stress as determined by the character of the stress deformation diagram of the cylinders (fixed by the proportions, consistency, kind, and age of concrete).

(2) **With age of concrete.**—For all practical purposes the percentage depth to the neutral axis for a given unit stress in the reinforcement may be taken as independent of the age of the concrete.

(3) **With modulus of elasticity of concrete.**—The character of the concrete as measured by its modulus of elasticity exerts an influence on the position of the neutral axis.

(*g*) VARIATION OF $\frac{M}{bd^2}$

(1) **With effective percentage of reinforcement.**—For any given percentage of effective reinforcement the moment of resistance varies as the ordinates of a straight line, and based on the moment

of resistance of a plain concrete beam the moment of resistance for a reinforced concrete beam is proportional to the effective percentage of reinforcement.

(2) **With character of concrete.**—The moment of resistance is appreciably affected by the character of the aggregate used and the age of the concrete.

(*h*) VARIATION OF THE DEFLECTION AT CENTER OF SPAN

(1) **With effective percentage of reinforcement and character of concrete.**—For a given unit stress in the reinforcement the deflection increases with the percentage of "effective" reinforcement and increases as the modulus of elasticity and ultimate strength of the concrete decreases.

(2) **With unit stress in the reinforcement.**—The deflection of a reinforced concrete beam increases in direct proportion to the increase in the unit stress in the reinforcement.

(*i*) VARIATION OF THE UNIT COMPRESSIVE STRESS IN THE EXTREME UPPER FIBER

(1) **With the effective percentage of reinforcement.**—The unit compressive stress in the extreme upper fiber varies with the percentage of effective reinforcement as the ordinates to a straight line.

(2) **With a given unit stress in the reinforcement.**—Excepting cinder concrete for the earlier ages and low percentages of effective reinforcement, the unit stress of 16 000 pounds per square inch in the reinforcement corresponds to a unit compressive stress in the extreme upper fiber of at least 1000 pounds per square inch.

2. CONCRETE IN COMPRESSION

The conclusions as to the general effect of age on the various elements (ultimate strength, initial modulus of elasticity, and yield point) that determine the value of a given concrete are probably of fairly general application.

(*a*) COMPARISON OF AGGREGATES

It should be recognized that the results obtained for each class of material—i. e., granites, limestones, gravels, etc.—used in these tests may not be applicable to other materials of the same class obtained from a different source. There are too many elements affecting the strength of concrete to warrant the assertion

that because an individual of a class—i. e., granite—gives excellent results, that therefore all granites will give equally good results. The gravel used in these tests had smooth round surfaces but developed a compressive strength but little inferior to that of the granite, and appreciably greater than that of the limestone. Yet it can not be stated that the use of any given gravel for concrete is permissible, because this particular sample, which originated from a hard flinty rock and is well graded, gives excellent results. A gravel deposit will necessarily partake of the physical properties of the rock from which it is derived and no good results can be hoped for by the use of a gravel which originated from a soft chalky limestone or from some weak cleavable shale or sandstone. The compressive strength of the stone affects the compressive strength of the concrete in which it is used in too great a degree to warrant the neglect of the consideration of this influence, while even for the same stone, the strength of the concrete will be greatly influenced by the uniformity or nonuniformity of the grading.

Again for equally good grading, the material which grades down from the larger particles will nearly always show the greater strength. The effect of a large amount of dust in decreasing the strength of the concrete should not be overlooked. It must be recognized that the quality of the sand used in making the concrete—i. e., its hardness, size, and grading, the presence of a large amount of very fine material—are all elements which will modify conclusions as to the excellence of a given stone or gravel.

From a consideration of the above facts it is always advisable to make careful investigation of the materials available, even though the costs of tests seem excessive.

(*b*) WEIGHT PER CUBIC FOOT OF CONCRETE

The weight per cubic foot for a 1:2:4 stone and gravel concrete may be taken as 150 pounds and a cinder concrete 120 pounds.

(*c*) ULTIMATE STRENGTH OF CONCRETES AT 4 WEEKS

The ultimate strength of 2000 pounds per square inch for a 1:2:4 concrete at the age of 4 weeks, frequently the basis for unit stresses, was exceeded by almost 50 per cent for the granite and gravel and by 25 per cent for the limestone concrete, but the

value found was 20 per cent less than 2000 pounds per square inch for the cinder concrete.

(*d*) EFFECT OF AGE ON ULTIMATE STRENGTH

The ultimate compressive strength of concrete shows a substantial increase from an age of 4 to one of 52 weeks, the strength at 4 weeks being about 65 per cent of that at 52 weeks.

(*e*) POSITION OF THE YIELD POINT

The yield point at the age of 4 weeks averages about 0.30 the ultimate strength and for stone and gravel concretes is well above 500 pounds per square inch, but for cinders is somewhat less. The yield point shows a substantial increase with age.

(*f*) COMPRESSIVE STRESS GROSS DEFORMATION DIAGRAM

The compressive stress, gross deformation diagram of concrete may be represented by a straight line up to a unit stress 1.5 times the yield point with a maximum error of about 6.5 per cent. A working formula for reinforced concrete in flexure, based on a constant stress deformation diagram for concrete in compression, will therefore give correct results up to an extreme unit fiber stress of 0.30, the ultimate strength. This would correspond to a factor of safety of about 3 and for a unit fiber stress 50 per cent greater the error will not exceed 7 per cent.

(*g*) INITIAL MODULUS OF ELASTICITY

The initial modulus of elasticity at the age of 4 weeks exceeds 2 500 000, the amount usually specified, by about 85 per cent for gravel, 70 per cent for granite, and 45 per cent for limestone concrete but is 35 per cent less for cinder concrete. The increase in stiffness with age as measured by the modulus of elasticity while marked is not nearly so great as the increase in strength.

(*h*) ULTIMATE STRENGTH OF CONCRETE

The ultimate strength of concrete in compression as given by the cylinder test is always less than that given by the cube test, the ratio being about 75 per cent at the age of 4 weeks, and showing a substantial increase with age due to the greater percentage increase of strength for the cylinders.

3. REINFORCEMENT

A study of the 1260 tests of the steel (Table 4) used as reinforcement for the beams herein recorded shows that—

(*a*) For even practically identical ultimate strengths there is considerable variation in the percentage of elongation and reduction of area.

(*b*) The yield point bears no relation to the ultimate strength.

WASHINGTON, JUNE 27, 1911.

Table 4.—Average Results of Tests on Reinforcement. One-half Inch Round Bars.

CINDER AGGREGATE

AGE OF BEAM, 4 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
417	2	36 960	36 960	54 630	37 520	30.3	70.4
418	2	37 070	37 720	57 920	35 730	28.5	68.0
419	2	37 070	37 390	53 080	37 520	29.5	70.8
429	3	39 710	39 090	57 950	39 970	29.3	68.2
430	3	39 030	40 490	58 010	38 690	28.1	67.8
431	3	39 530	41 300	57 420	37 340	30.5	67.2
441	4	39 200	40 520	57 400	37 970	29.1	67.2
442	4	39 610	41 840	57 840	38 750	27.8	68.1
443	4	39 750	41 150	59 350	39 460	28.0	64.5
453	5	37 330	40 330	56 000	38 040	28.9	69.8
454	5	36 910	38 210	56 130	37 880	28.4	66.1
455	5	37 520	39 750	55 000	35 660	29.5	69.1
465	6	35 620	36 980	53 430	36 800	29.8	69.4
466	6	35 500	37 870	54 300	37 780	29.0	68.6
467	6	35 470	37 350	56 440	38 400	30.0	69.4
477	7	33 880	36 730	57 050	38 970	28.0	67.8
478	7	33 180	35 790	53 690	35 810	29.5	69.1
479	7	33 690	37 620	53 560	37 860	30.4	69.8
489	8	36 030	38 020	54 810	37 050	29.2	69.5
490	8	35 910	37 690	54 580	36 970	28.8	71.0
491	8	35 680	37 950	55 420	38 550	30.2	69.4

AGE OF BEAM, 13 WEEKS

420	2	37 750	38 400	55 850	37 670	28.8	69.8
421	2	37 440	39 200	61 130	44 090	27.5	59.7
422	2	37 020	40 010	57 810	37 650	28.5	66.3
432	3	39 020	39 860	55 460	36 380	29.8	68.2
433	3	38 630	39 550	57 810	36 990	29.3	69.1
434	3	39 300	40 520	58 140	36 650	28.0	65.2
444	4	39 220	39 900	56 550	38 340	32.3	67.8
445	4	38 230	39 780	56 640	36 420	29.9	67.8
446	4	39 490	41 670	57 810	37 180	28.9	68.5
456	5	37 320	38 780	52 840	36 420	30.7	70.0
457	5	37 160	38 000	54 150	35 750	29.3	70.4
458	5	37 650	40 810	56 770	39 490	29.3	67.4
468	6	35 660	38 010	55 280	39 590	30.1	67.8
469	6	35 380	37 970	52 710	36 270	31.9	69.9
470	6	35 380	37 630	54 630	37 390	30.6	69.8
480	7	34 180	36 110	53 260	35 700	30.7	66.1
481	7	34 240	36 260	54 610	37 640	31.3	69.1
482	7	33 810	36 980	56 450	40 120	29.6	69.1
492	8	36 060	37 210	54 260	37 330	30.9	70.3
493	8	35 580	38 190	56 740	37 450	29.5	67.2
494	8	35 710	36 440	53 120	36 680	29.9	71.1

Table 4.—Average Results of Tests on Reinforcement. One-half Inch Round Bars—Continued

CINDER AGGREGATE—Continued

AGE OF BEAM, 26 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
423	2	37 440	38 220	55 900	37 040	30.0	69.8
424	2	37 220	38 770	53 560	34 600	30.3	70.2
425	2	37 920	39 680	56 100	36 660	28.5	69.6
435	3	39 740	40 230	55 510	35 650	29.0	68.5
436	3	38 990	40 450	57 260	37 480	29.5	66.8
437	3	39 630	40 480	59 580	40 000	29.0	65.3
447	4	39 270	41 350	57 340	38 260	28.7	67.4
448	4	39 240	40 850	56 970	44 630	28.5	67.2
449	4	38 970	39 740	56 860	38 350	29.1	67.7
459	5	36 960	38 950	54 280	36 830	28.7	70.2
460	5	37 590	39 050	57 100	47 430	29.4	68.7
461	5	35 970	36 880	53 890	36 730	30.7	69.0
471	6	34 980	38 100	54 630	38 010	30.1	70.2
472	6	35 160	36 800	54 340	36 420	30.5	70.4
473	6	35 650	37 940	54 770	38 380	29.0	68.7
483	7	33 800	35 920	54 080	35 910	30.2	70.3
484	7	34 160	36 460	54 030	37 330	28.8	70.3
485	7	33 930	36 880	52 340	36 370	30.7	69.0
495	8	35 530	37 140	54 660	38 470	30.4	70.5
496	8	35 520	36 790	53 500	36 510	31.4	71.7
497	8	36 600	37 820	54 730	39 250	30.3	70.2

AGE OF BEAM, 52 WEEKS

426	2	37 160	38 890	56 200	37 090	31.5	69.9
427	2	36 720	38 480	54 030	35 930	30.8	69.7
428	2	38 290	37 760	55 730	36 220	31.5	71.4
438	3	39 230	40 290	58, 190	36 740	28.3	66.0
439	3	39 860	40 850	56 300	37 870	31.2	70.7
440	3	39 410	41 040	56 690	36, 140	29.2	68.8
450	4	40 520	41 630	58 350	38 040	29.6	66.8
451	4	39 690	41 050	59 750	40 030	29.9	67.5
452	4	39 590	40 610	58 600	38 190	28.4	65.7
462	5	35 930	37 420	54 720	36 240	29.2	70.7
463	5	35 570	37 460	55 200	36 810	30.0	70.0
464	5	35 760	38 800	55 390	36 590	28.4	70.0
474	6	33 120	36 710	60 390	40 120	28.4	64.5
475	6	34 300	38 770	56 800	37 830	30.6	67.7
476	6	34 620	37 400	56 100	38 860	31.0	69.2
486	7	34 080	37 620	53 660	37 020	30.3	68.9
487	7	34 150	37 230	53 160	37 120	30.9	70.2
488	7	34 220	37 230	53 010	34 670	31.3	71.1
498	8	35 940	37 760	54 980	36 880	30.1	69.4
499	8	36 530	38 620	54 880	38 070	29.0	70.0
500	8	35 750	37 760	55 100	36 770	29.1	68.4

Table 4.—Average Results of Tests on Reinforcement. One-Half Inch Round Bars—Continued

GRANITE AGGREGATE

AGE OF BEAM, 4 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
162	2	40 230	42 610	60 010	40 340	27.9	61.1
163	2	39 180	42 560	56 930	39 590	28.8	67.6
164	2	39 760	42 300	57 370	37 270	28.5	69.5
174	3	38 870	42 150	56 530	37 740	28.4	67.9
175	3	39 490	42 130	55 670	34 410	29.6	67.7
176	3	39 530	42 780	56 870	35 960	28.6	69.4
186	4	39 360	42 840	58 160	39 970	28.0	64.9
187	4	39 950	42 540	57 760	36 890	28.8	69.2
188	4	39 850	43 750	57 980	38 390	28.7	66.0
198	5	39 460	42 180	56 550	35 910	29.3	66.2
199	5	39 650	42 210	58 070	40 500	28.1	67.5
200	5	39 190	43 020	58 780	40 930	28.4	65.3
210	6	39 640	42 220	59 130	41 460	29.7	66.0
211	6	(1)					
212	6	(1)					
222	7	39 660	42 100	58 640	41 140	28.7	63.3
223	7	39 330	42 020	57 430	38 660	29.8	68.3
224	7	39 450	42 300	59 220	40 580	29.5	66.1
237	8	37 240	41 650	54 870	33 900	29.9	68.5
238	8	37 260	41 720	55 480	36 780	29.4	68.9
239	8	37 560	42 200	56 790	37 330	29.3	66.9

AGE OF BEAM, 13 WEEKS

165	2	39 460	42 230	56 020	37 400	28.2	70.8
166	2	39 180	42 200	57 740	41 420	29.4	67.3
167	2	39 350	41 910	56 330	37 160	29.4	69.6
177	3	39 520	41 940	58 430	37 900	29.9	65.6
178	3	38 900	43 390	55 860	41 110	29.8	69.9
179	3	39 580	43 470	58 150	37 860	28.1	66.8
189	4	38 920	41 960	56 040	35 940	30.0	70.7
190	4	39 680	42 480	58 910	39 010	28.9	66.8
191	4	39 440	40 670	58 780	43 150	27.6	63.5
201	5	39 680	40 920	60 530	42 320	28.8	63.4
202	5	39 820	41 460	60 140	44 730	28.5	61.6
203	5	39 820	40 410	59 760	42 390	29.5	64.0
213	6	39 840	41 460	59 010	40 860	29.5	65.3
214	6	39 970	41 230	58 780	44 260	30.4	64.2
215	6	39 310	41 080	56 630	37 620	29.9	65.4
225	7	38 920	41 180	61 650	45 820	28.2	61.1
226	7	39 290	42 110	60 200	46 050	28.1	64.5
227	7	39 120	40 750	60 520	42 200	29.8	63.5
243	8	37 580	41 790	57 740	38 400	29.2	67.7
244	8	37 480	41 780	56 860	37 240	28.9	67.9
245	8	37 300	41 400	55 470	36 040	29.8	67.4

[1] Tags of steel numbers mixed. The average elastic limit in these two beams was 39 000 to 40 000.

Table 4.—Average Results of Tests on Reinforcement. One-Half Inch Round Bars—Continued

GRANITE AGGREGATE—Continued

AGE OF BEAM, 26 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
168	2	39 290	43 160	59 560	43 730	26.9	56.9
169	2	39 700	42 810	57 620	39 330	29.4	69.8
170	2	39 460	42 520	60 080	40 650	26.6	65.1
180	3	39 750	42 700	56 920	38 390	29.2	68.3
181	3	39 300	41 320	56 860	43 320	28.4	58.9
182	3	39 480	43 730	58 650	43 750	27.0	65.7
192	4	40 320	42 570	59 440	41 440	28.5	66.4
193	4	38 670	41 350	56 720	35 810	30.2	69.1
194	4	39 420	42 800	59 460	38 680	29.1	66.7
204	5	39 840	41 380	61 510	46 450	27.8	63.2
205	5	39 720	42 700	64 040	49 830	26.7	60.4
206	5	39 630	41 340	61 420	49 420	28.5	61.2
216	6	40 000	41 680	59 020	44 340	28.8	65.3
217	6	39 450	41 930	59 690	40 500	29.0	66.1
218	6	39 190	41 420	58 350	42 380	28.7	66.6
231	7	37 040	40 960	55 740	36 620	28.5	69.0
232	7	37 990	40 450	55 330	38 110	29.0	67.3
233	7	37 230	40 610	55 370	40 850	29.7	67.9
240	8	37 880	42 170	56 190	37 620	28.9	68.9
241	8	37 070	40 760	55 270	36 700	29.5	69 3
242	8	37 430	42 400	55 950	37 420	29.6	69.1

AGE OF BEAM, 52 WEEKS

171	2	38 640	42 480	57 360	38 290	28.1	67.2
172	2	39 430	42 480	57 690	36 820	28.1	68.1
173	2	38 900	42 760	56 800	39 190	30.3	68.0
183	3	39 420	43 000	57 670	37 150	28.4	66.8
184	3	39 850	42 190	58 040	38 440	29.5	68.9
185	3	39 760	40 910	54 300	36 920	30.0	68.9
195	4	39 350	42 560	57 790	39 660	29.0	67.5
196	4	38 530	42 170	57 590	40 370	29.0	68.2
197	4	38 890	42 230	56 230	36 800	29.2	69.0
207	5	39 460	41 040	59 710	39 720	28.5	65.4
208	5	39 210	41 910	56 890	40 320	28.6	67.7
209	5	39 290	42 090	58 500	39 980	29.0	67.2
219	6	39 470	41 800	59 540	40 480	30.0	65.3
220	6	39 380	41 360	59 130	41 520	29.3	64.4
221	6	39 440	42 900	58 030	36 920	28.5	68.4
228	7	37 040	40 950	56 800	39 020	29.5	68.1
229	7	37 310	40 610	54 370	36 890	29.5	69.6
230	7	37 260	40 430	55 100	38 390	29.0	67.1
234	8	37 370	41 460	56 480	38 300	29.2	67.5
235	8	37 790	42 440	56 340	36 400	29.1	68.4
236	8	37 670	41 730	55 210	35 850	29.9	68.8

Table 4.—Average Results of Tests on Reinforcement One-half Inch Round Bars—Continued

GRAVEL AGGREGATE

AGE OF BEAM, 4 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
333	2	40 990	43 500	60 380	40 020	29.1	64.2
334	2	41 090	41 910	59 460	41 970	27.5	64.0
335	2	41 730	44 930	71 330	61 850	25.1	57.9
345	3	41 440	41 440	61 150	41 990	28.8	65.7
346	3	41 160	43 640	59 770	40 940	26.7	63.8
347	3	41 200	43 760	58 660	36 640	29.6	68.5
357	4	41 000	43 460	63 880	49 020	26.3	65.0
358	4	41 380	42 410	57 150	38 310	29.6	65.8
359	4	40 910	41 930	75 150	61 820	24.6	55.1
369	5	39 040	40 270	59 520	41 910	27.4	66.6
370	5	39 320	39 930	56 640	39 010	28.0	65.3
371	5	39 540	39 540	56 630	39 300	28.6	65.5
381	6	37 300	38 010	55 510	40 310	29.9	69.9
382	6	37 410	38 570	56 060	39 160	29.1	68.7
383	6	37 600	39 170	54 900	38 410	29.6	69.3
393	7	38 170	39 650	56 570	38 240	29.8	66.6
394	7	37 800	39 120	55 630	40 140	30.0	68.5
395	7	37 790	40 030	54 210	36 120	29.4	69.4
405	8	37 370	38 360	55 560	38 590	29.2	69.0
406	8	37 530	38 680	57 060	37 940	28.9	68.9
407	8	37 530	38 590	55 590	38 390	29.1	68.5

AGE OF BEAM, 13 WEEKS

336	2	40 860	42 590	59 390	39 030	28.9	64.3
337	2	40 570	41 530	61 150	46 120	26.9	65.5
338	2	41 170	42 370	60 300	44 140	28.8	63.6
348	3	40 650	42 010	57 510	39 660	28.0	68.1
349	3	40 120	41 330	56 870	37 920	29.2	67.9
350	3	41 250	43 390	59 760	40 500	26.6	64.2
360	4	41 080	43 310	60 350	46 490	28.7	65.4
361	4	39 520	39 830	57 540	37 230	29.3	68.0
362	4	39 050	40 040	57 930	38 840	29.3	66.2
372	5	39 090	39 510	56 680	38 280	28.9	68.6
373	5	39 460	39 900	57 640	43 030	28.4	67.5
374	5	38 920	39 830	57 710	38 620	29.4	67.7
384	6	37 270	37 950	56 160	37 650	29.0	67.4
385	6	37 280	37 470	55 230	39 160	30.6	69.9
386	6	37 330	38 050	56 190	38 710	29.8	69.0
396	7	37 420	38 080	55 450	37 590	29.9	69.7
397	7	37 820	41 020	57 420	42 160	28.8	68.8
398	7	37 820	38 920	57 910	40 590	29.4	67.7
408	8	37 400	38 940	55 960	37 610	29.1	66.8
409	8	37 590	38 630	55 660	37 490	29.0	66.4
410	8	37 240	38 110	55 780	37 420	29.8	67.6

Table 4.—Average Results of Tests on Reinforcement. One-half Inch Round Bars—Continued

GRAVEL AGGREGATE—Continued

AGE OF BEAM, 26 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
339	2	42 160	42 160	62 510	48 650	26.9	57.8
340	2	41 530	45 220	71 680	63 720	21.9	45.9
341	2	40 700	40 700	58 350	40 560	31.6	56.3
351	3	41 120	42 110	60 100	41 810	29.0	63.4
352	3	41 360	43 960	64 690	55 330	24.5	60.5
353	3	40 990	43 140	58 880	45 470	30.0	67.5
363	4	39 280	39 400	56 830	39 140	28.3	68.3
364	4	39 400	40 310	58 440	43 720	28.3	66.0
365	4	39 230	39 680	57 790	41 560	28.6	68.7
375	5	39 090	39 850	57 840	39 030	28.0	68.3
376	5	39 000	39 660	57 840	40 590	28.9	67.9
377	5	38 960	39 680	57 430	41 050	28.0	68.4
387	6	37 100	38 400	56 010	38 030	29.1	69.2
388	6	37 340	38 120	57 670	38 830	28.2	68.0
389	6	37 390	38 540	55 820	38 930	29.4	67.9
399	7	37 460	39 050	55 790	39 180	28.8	67.9
400	7	37 120	38 250	57 750	38 700	30.0	68.7
401	7	37 740	38 740	55 990	41 190	29.4	67.7
411	8	37 630	38 120	55 620	36 550	30.1	68.4
412	8	37 290	38 240	55 580	36 740	29.2	69.1
413	8	37 420	38 620	56 080	36 890	28.7	68.1

AGE OF BEAM, 52 WEEKS

342	2	41 380	43 870	61 610	47 400	26.9	59.4
343	2	41 130	42 520	62 180	52 480	26.9	61.0
344	2	42 840	46 030	69 800	54 780	25.0	56.5
354	3	42 030	44 280	67 050	55 600	25.9	59.3
355	3	41 180	42 980	59 810	39 700	29.2	65.2
356	3	41 080	42 880	59 260	57 600	28.1	66.1
366	4	39 320	40 480	58 850	40 130	28.4	66.7
367	4	39 170	40 030	59 200	40 440	29.1	67.5
368	4	39 220	39 810	56 790	38 200	29.1	67.5
378	5	37 610	38 090	56 280	39 240	30.4	68.6
379	5	37 220	37 850	56 260	39 550	28.4	67.9
380	5	37 300	38 180	55 810	40 710	28.6	68.9
390	6	37 560	39 330	55 670	40 720	29.2	67.9
391	6	37 310	38 050	55 360	41 490	29.2	68.9
392	6	37 240	38 510	56 350	40 040	29.1	68.8
402	7	37 890	38 580	54 560	38 640	28.8	68.9
403	7	38 300	38 910	56 100	53 800	29.7	69.2
404	7	37 620	38 970	57 120	38 300	28.5	68.0
414	8	37 460	38 670	55 810	37 090	29.4	69.9
415	8	37 080	38 320	55 350	36 680	29.6	69.9
416	8	37 560	38 940	53 570	37 010	30.6	68.5

Table 4.—Average Results of Tests on Reinforcement. One-Half Inch Round Bars—Continued

LIMESTONE AGGREGATE

AGE OF BEAM, 4 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
255	2	37 770	42 350	55 920	35 030	30.3	68.1
256	2	38 120	41 200	59 300	40 490	29.7	65.7
257	2	37 320	41 410	53 590	31 470	30.0	70.6
261	3	37 530	40 720	55 260	33 940	28.7	70.5
262	3	37 780	41 080	56 190	34 140	29.0	70.9
263	3	36 810	41 330	56 750	35 770	30.2	67.0
273	4	37 570	40 720	61 020	45 640	28.2	63.3
274	4	37 720	40 280	57 970	41 570	29.4	62.8
275	4	37 550	41 370	59 360	39 790	28.9	61.9
285	5	38 200	42 550	58 900	41 520	29.3	66.0
286	5	37 790	41 850	55 540	35 570	30.5	68.8
287	5	37 350	41 030	59 360	42 210	28.6	65.4
297	6	35 450	40 330	54 490	38 060	27.2	68.5
298	6	35 870	40 790	55 620	37 390	30.0	68.7
299	6	35 850	40 660	54 780	36 030	30.9	69.3
318	7	35 690	42 620	62 560	48 830	27.7	63.9
319	7	35 570	39 740	55 560	39 530	30.1	64.9
320	7	35 760	40 900	55 460	38 030	29.7	68.2
321	8	35 900	39 210	55 270	39 150	29.5	68.2
322	8	35 920	37 140	53 680	38 550	30.1	68.8
323	8	35 790	37 760	55 370	38 770	28.8	68.7

AGE OF BEAM, 13 WEEKS

249	2	36 970	41 800	57 140	39 480	27.6	70.9
250	2	37 620	41 350	56 260	37 890	27.9	69.9
251	2	37 800	40 740	60 690	43 240	30.0	63.9
264	3	37 760	42 980	57 870	36 000	29.8	67.7
265	3	37 590	42 160	60 200	43 280	28.9	64.6
266	3	37 350	40 040	59 080	41 840	27.5	64.2
276	4	37 310	41 500	57 240	40 930	28.9	66.9
277	4	37 240	42 020	58 670	44 440	29.1	67.2
278	4	37 520	40 540	58 930	40 340	29.3	66.1
288	5	35 710	40 000	54 920	37 000	30.3	69.3
289	5	35 970	40 150	58 200	42 180	28.9	66.7
290	5	35 330	40 280	53 660	37 610	30.5	67.5
300	6	35 840	40 050	53 940	37 030	29.1	68.1
301	6	35 580	40 740	54 640	36 460	29.2	70.3
302	6	35 510	40 570	56 160	38 250	30.3	68.7
312	7	35 230	41 120	56 670	37 790	29.8	68.6
313	7	35 970	40 070	58 430	42 510	29.3	68.1
314	7	36 440	40 440	56 420	38 070	30.6	67.9
324	8	35 900	37 250	54 170	37 600	30.6	68.7
325	8	35 760	37 730	55 950	38 520	28.8	70.2
326	8	35 710	36 830	54 310	37 940	30.4	69.5

Table 4.—Average Results of Tests on Reinforcement. One-Half Inch Round Bars—Continued

LIMESTONE AGGREGATE—Continued

AGE OF BEAM, 26 WEEKS

Reinforcement used in Beam No.	No. of Bars	Elastic Limit (by Dividers)	Yield Point (Drop of Beam)	Maximum Unit Stress	Breaking Strength	Percentage Elongation in 8 Inches	Percentage Reduction in Area
252	2	37 560	40 750	53 140	34 680	29.4	73.4
253	2	37 450	41 650	56 020	36 140	31.3	70.1
254	2	37 830	40 290	57 620	41 020	30.7	68.2
267	3	37 270	40 680	56 480	37 750	26.9	66.6
268	3	37 580	40 750	58 940	42 460	28.3	63.6
269	3	37 310	40 710	53 090	36 350	29.2	71.4
279	4	37 250	41 040	58 230	41 320	29.7	65.1
280	4	38 130	40 990	58 140	37 360	31.6	67.4
281	4	37 530	41 090	58 890	42 650	30.3	65.6
291	5	35 840	39 800	53 780	37 110	29.5	66.9
292	5	35 820	39 990	54 090	38 090	30.5	68.7
293	5	35 980	40 300	55 150	37 410	30.2	69.2
303	6	34 940	41 890	58 350	39 730	30.0	66.3
304	6	36 080	41 350	53 810	37 590	30.0	68.0
305	6	35 920	41 060	54 590	36 140	30.0	69.7
315	7	35 460	39 600	54 550	37 510	30.3	68.6
316	7	35 530	37 530	54 410	40 300	29.1	67.4
317	7	35 900	39 870	54 940	39 600	30.0	65.8
327	8	35 740	36 730	54 990	38 000	30.0	69.8
328	8	35 960	37 140	54 440	37 460	30.5	69.3
329	8	35 910	36 900	55 220	33 240	29.7	69.7

AGE OF BEAM, 52 WEEKS

246	2	36 870	41 100	54 900	37 670	29.1	70.0
247	2	37 670	41 230	53 990	37 220	30.0	70.6
248	2	36 840	40 680	56 940	38 580	28.5	67.5
270	3	37 260	41 900	60 600	41 770	29.0	63.2
271	3	38 670	41 890	58 650	42 530	29.2	67.0
272	3	37 440	41 660	62 110	44 710	28.8	63.2
282	4	37 730	41 040	59 100	40 800	28.3	66.8
283	4	37 240	40 990	57 690	38 420	30.4	67.6
284	4	37 930	42 210	57 340	40 740	29.1	65.1
294	5	35 870	39 720	53 930	38 140	30.4	67.3
295	5	36 350	40 270	55 490	40 250	30.3	69.4
296	5	36 070	40 840	55 450	39 280	31.0	69.2
306	6	35 300	39 650	53 890	37 930	30.9	68.7
307	6	36 210	40 770	56 390	39 210	28.7	66.9
308	6	35 760	40 440	54 240	35 850	30.1	68.2
309	7	35 690	40 590	55 580	35 670	30.7	70.1
310	7	35 940	39 750	56 000	40 740	29.2	68.2
311	7	35 730	40 820	55 460	37 180	31.2	70.6
330	8	36 210	36 790	59 550	38 290	29.8	70.4
331	8	36 020	37 510	55 930	38 020	29.6	70.7
332	8	36 000	38 720	56 790	37 790	28.4	67.8

SUMMARY OF TESTS ON REINFORCED CONCRETE BEAMS

Table 6.—Granite Concrete Proportions, 1:2:4. Age, 4 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D−.35KD in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
162	1170	145.4	2	0.49	0.49	0.393	3000	0.000137	5900	(0.356)	(0.001100)	(33 000)	42 610	0.77	5500	0.001014	30 400	3.18	8.89	106 100	151 900	0.70	0.000472	1780	[illegible]	1205	0.47	[illegible]	120
163	1200	145.5	2	.49	.49	.393	2500	.000124	7000	.395	(.001492)	(44 800)	42 560	1.05	6750	.001415	42 500	2.67	9.07	151 400	182 400	.83	.000516	1900	1405	1695	.74	.89	[illegible]
164	1230	151.9	2	.49	.49	.393	3000	.000150	6500	(.340)	(.001240)	(37 200)	42 300	.88	6250	.001200	36 000	2.53	9.11	128 800	170 900	.75	.000406	1600	1255	1675	.78	1.05	131
Average									6470	.364	(.001277)	(38 300)		.90								.76				.66	.87	130
174	1200	150.1	3	.74	.74	.589	3000	[1].000269	9300	.415	(.001135)	(34 100)	42 150	.81	9000	.001068	32 000	3.83	8.66	163 300	236 400	.69	.000665	2230	1105	1600	.50	.72	125
175	1190	148.7	3	.74	.74	.589	2500	.000131	8900	.445	.001246	37 400	42 130	.89	8750	.001234	37 000	3.54	8.76	190 900	230 200	.83	.000677	2250	1365	1670	.62	.74	121
176	1200	150.3	3	.74	.74	.589	2500	.000124	9000	(.430)	(.001431)	(42 900)	42 780	1.00	8750	.001332	40 000	3.50	8.78	206 900	230 400	.90	.000717	2320	1515	1685	.65	.73	120
Average									9070	.430	.001271	38 500		.90								.81				.59	.73	122
[illegible]	1210	146.6	4	.98	.98	.785	2400	.000095	13 280	.460	(.001340)	(40 200)	42 840	.94	13 000	.001320	39 600	3.69	8.71	270 900	332 500	.81	.000772	2410	[illegible]	2340	.79	.97	[illegible]
187	1190	146.2	4	.98	.98	.785	2000	.000086	11 650	.450	(.001369)	(41 100)	42 540	.97	11 000	.001191	35 700	3.64	8.73	244 800	284 200	.86	.000682	2260	1735	2020	.77	[illegible]	111
[illegible]	1210	145.2	4	.98	.98	.785	4000	[2].000223	12 460	.465	(.001409)	(42 300)	43 750	.97	12 000	.001328	39 800	3.54	8.76	273 800	308 500	.89	.000727	2340	1985	2230	.85	.95	120
Average									12 460	.458	(.001373)	(41 200)		.96								.85				.80	.94	120
198	1230	149.8	5	1.23	1.11	.982	3000	.000128	14 000	(.487)	(.001429)	(42 900)	42 180	1.02	13 500	.001344	40 300	3.84	8.66	291 400	344 900	.84	.000839	2510	2095	2495	.83	.99	[illegible]
199	1230	150.4	5	1.23	1.11	.982	3000	.000139	14 000	(.488)	(.001497)	(44 900)	42 210	1.06	13 500	.001390	41 700	3.80	8.67	301 900	344 900	.88	.000850	[3] 2520	2190	2490	.87	.99	127
200	1230	147.9	5	1.23	1.11	.982	3500	[5].000155	13 750	(.475)	(.001412)	(42 400)	43 020	.99	13 500	.001386	41 600	3.75	8.69	302 200	344 900	.88	.000831	2500	2215	2515	.89	1.01	127
Average									13 920	(.483)	(.001446)	(43 400)		1.02								.87				.86	1.00	127
210	1220	147.6	6	1.47	1.30	1.178	2500	.000103	16 000	.555	(.001559)	(46 800)	42 220	1.11	15 000	.001282	38 500	4.06	8.58	314 500	387 000	.83	.000877	[3] 2560	2195	2645	.86	1.03	124
211	1210	144.0	6	1.47	1.30	1.178	2500	.000110	15 500	.535	(.001538)	(46 100)	[4]	.....	14 000	.001277	38 300	3.89	8.64	316 500	356 500	.89	.000814	2480	2290	2575	.92	1.04	115
212	1200	146.9	6	1.47	1.30	1.178	2500	.000117	15 100	.635	(.001687)	(50 600)	[4]	.....	14 000	.001311	39 300	4.08	8.57	320 600	356 400	.90	.000901	[3] 2590	2230	[illegible]	.86	.96	117
Average									15 530	.575	(.001595)	(47 800)		1.11								.87				.88	1.01	119
222	1240	150.4	7	1.72	1.54	1.375	3500	.000157	18 000	.600	(.001679)	(50 400)	42 100	1.20	17 500	.001398	41 900	4.53	8.41	400 600	441 000	.91	.001159	[3] 2810	2525	2775	.90	.99	123
223	1230	148.2	7	1.72	1.54	1.375	3000	.000153	19 200	.630	(.001809)	(54 300)	42 020	1.29	18 000	.001465	44 000	4.31	8.49	426 800	452 900	.94	.001108	[3] 2770	2600	2980	1.01	1.08	124
224	1220	146.8	7	1.72	1.54	1.375	3000	.000146	18 450	.650	(.001933)	(58 000)	42 300	1.37	17 000	.001398	41 900	4.28	8.50	407 200	428 700	.95	.001045	[3] 2720	2685	2828	.99	1.04	117
Average									18 550	.627	(.001807)	(54 200)		1.29								.93				.97	1.04	121
237	1220	146.8	8	1.96	1.72	1.571	3500	.000117	19 650	.640	(.001474)	(44 200)	41 650	1.06	19 000	.001335	40 100	4.87	8.30	413 000	476 700	.87	.001268	[3] 2860	2485	2855	.87	1.00	123
238	1240	150.1	[illegible]	1.96	1.72	1.571	3000	.000152	19 150	.560	(.001679)	(50 400)	41 720	1.21	18 000	.001344	40 300	4.38	8.47	429 800	453 000	.95	.001045	[3] 2720	2815	2965	1.03	1.09	113
239	1240	147.2	8	1.96	1.72	1.571	4000	.000176	19 920	.625	(.001774)	(53 200)	42 200	1.26	19 000	.001426	42 800	4.46	8.44	453 800	477 000	.95	.001148	[3] 2800	2930	3085	1.05	1.10	119
Average									19 570	.608	(.001642)	(49 300)		1.18								.92				.98	1.06	118
Grand Ave		147.9					2900	.000130																			.95	122

[1] Beam was dropped when being placed in machine. [2] Accidentally loaded to 4000 lbs. before test. [3] Value taken from curve produced. [4] Steel was mixed. [5] Accidentally loaded to 3900 lbs. before test.

Remarks.—Average bond stress developed in beam=122 lbs. per square inch. Average ultimate bond stress from bond test pieces=489 lbs. per square inch. Ratio=4.0.

Note.—Values in parentheses are estimated.

Table 7.—Granite Concrete Proportions, 1:2:4. Age, 13 Weeks

165	1200	149.1	2	0.49	0.49	0.393	2000	0.000072	6800	0.350	0.001138	34 100	42 230	0.81	6500	0.001015	30 500	3.06	8.93	107 000	176 400	0.61	0.000447	[illegible]	880	1445	0.47	0.76	[illegible]
166	1190	147.7	2	.49	.49	.393	3000	.000105	6500	.325	.001176	35 300	42 200	.84	6500	.001176	35 300	2.62	9.08	125 900	176 200	.72	.000418	1780	1190	1655	.67	.93	135
167	1210	150.3	2	.49	.49	.393	2500	.000096	6600	.345	.001164	34 900	41 910	.83	6500	.001147	34 400	2.84	9.01	121 700	176 500	.69	.000454	1930	1070	1550	.55	.80	137
Average									6630	.340	.001159	34 800		.83								.67				.56	.83	137
177	1200	148.2	[illegible]	.74	.74	.589	3000	.000121	9210	.410	.001215	36 500	41 940	.87	9000	.001157	34 700	3.13	8.90	181 900	236 400	.77	.000527	2180	1470	1910	.67	.88	122
178	1200	146.6	[illegible]	.74	.74	.589	3000	.000109	10 000	.410	.001248	37 400	43 390	.86	10 000	.001248	37 400	3.10	8.92	196 500	260 400	.75	.000560	2300	1600	2135	.70	.93	133
179	1200	146.8	3	.74	.74	.589	4000	.000149	9840	.390	.001070	32 100	43 470	.74	9000	.000949	28 500	3.44	8.80	147 700	236 400	.62	.000498	[illegible]	1100	1775	.53	.85	123
Average									9680	.403	.001178	35 300		.82								.71				.63	[illegible]	126
189	1240	152.7	4	.98	.98	.785	4000	.000139	12 700	.455	.001226	36 800	41 950	.88	12 000	.001125	33 800	3.66	8.72	231 500	309 000	.75	.000650	2600	1630	2175	.63	[illegible]	121
190	1190	146.2	4	.98	.98	.785	3000	.000094	12 560	.475	.001374	41 200	42 480	.97	12 500	.001344	40 300	3.37	8.82	279 200	320 200	.87	.000682	2690	2115	2430	.79	.90	124
191	1200	147.8	4	.98	.98	.785	4000	.000142	11 780	.400	.001176	35 300	40 670	.87	11 000	.001021	30 600	3.66	8.72	209 600	284 400	.74	.000588	2390	1475	1995	.62	.83	112
Average									12 350	.443	.001259	37 800		.91								.79				.68	.86	119
201	1210	146.2	5	1.23	1.11	.982	4000	.000125	13 000	.430	.001443	43 300	40 920	1.06	13 000	.001164	34 900	3.61	8.74	255 600	332 500	.77	.000657	2610	1935	2515	.74	.96	121
202	1210	147.2	[illegible]	1.23	1.11	.982	3000	.000112	13 650	.435	.001323	39 700	41 460	.96	13 000	.001215	36 500	3.55	8.76	268 200	332 500	.81	.000670	2650	2060	2545	.78	.96	121
203	1210	148.1	[illegible]	1.23	1.11	.982	4000	.000143	14 180	.465	.001479	44 400	40 410	1.10	13 000	.001166	35 000	3.53	8.76	257 300	332 500	.77	.000637	[illegible]	1985	2580	.78	1.01	121
Average									13 810	.443	.001415	42 500		1.04								.78				.77	.98	121
213	1230	149.1	6	1.47	1.30	1.178	3000	.000106	16 550	.470	.001321	39 600	41 460	.96	16 000	.001279	38 400	3.79	8.67	319 200	404 900	.79	.000782	[illegible]	2360	2985	.79	1.00	130
214	1210	147.3	[illegible]	1.47	1.30	1.178	3000	.000103	16 800	.525	.001494	44 800	41 230	1.09	16 000	.001321	39 600	3.78	8.68	329 600	404 500	.81	.000803	3040	2440	3010	.80	.99	[illegible]
215	1240	152.1	6	1.47	1.30	1.178	4000	.000147	16 500	.495	.001422	42 700	41 080	1.04	16 000	.001368	41 000	3.69	8.71	343 100	405 000	.85	.000799	3030	2595	3055	.86	1.01	129
Average									16 620	.497	.001412	42 400		1.03								.82				.82	[illegible]	129
225	1220	147.7	7	1.72	1.54	1.375	3000	.000096	18 250	.510	.001503	45 100	41 180	1.10	18 000	.001354	40 600	4.03	8.59	400 900	452 700	.89	.000913	3330	[illegible]	3125	.83	[illegible]	122
226	1230	147.3	[illegible]	1.72	1.54	1.375	4000	.000124	18 620	.505	.001694	50 800	42 110	1.21	18 000	.001321	39 600	3.85	8.65	396 200	452 900	.87	.000827	3100	2850	3275	.92	1.06	121
227	1240	150.4	7	1.72	1.54	1.375	4000	.000133	18 780	.495	.001443	43 300	40 750	1.06	18 000	.001308	39 200	3.94	8.62	389 200	453 000	.86	.000850	3170	2750	[illegible]	.87	1.01	121
Average									18 550	.503	.001547	46 400		1.12								.87				.87	[illegible]	121
243	1240	147.6	[illegible]	1.96	1.72	1.571	3000	.000095	21 300	.615	.001706	51 200	41 790	1.23	19 000	.001215	36 500	4.30	8.50	391 500	477 000	.82	.000917	3330	[illegible]	3175	.78	[illegible]	[illegible]
244	1260	149.8	[illegible]	1.96	1.72	1.571	4000	.000113	21 280	.530	.001405	42 200	41 780	1.01	20 000	.001252	37 600	4.07	8.58	409 600	501 400	.82	.000860	[illegible]	[illegible]	[illegible]	.89	[illegible]	[illegible]
245	1250	149.2	[illegible]	1.96	1.72	1.571	4000	.000131	22 120	.595	.001831	54 900	41 400	1.33	19 000	.001198	35 900	4.03	8.59	391 900	477 200	.82	.000809	3060	2755	3360	.90	1.10	116
Average									21 570	.580	.001647	49 400		1.19								.82				.86	1.05	119
Grand Ave		148.5					3400	.000117																			.94	[illegible]

Remarks.—Average bond stress developed in beam=125 pounds per square inch. Average ultimate bond stress from bond test pieces=611 pounds per square inch. Ratio=4.9.

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Table 8.—Granite Concrete Proportions, 1:2:4. Age, 26 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ¾" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D−.35KD in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Oppressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	Unit Oppressive Stress Upper Fiber, lbs. per sq. in.: C_2 from Resisting Moment	Unit Oppressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Bending Moment	$C_2 \div C_1$	$C_2 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
169	1210	148.8	II	.49	.49	.393	2500	0.000082	6810	0.340	0.001178	35 300	42 810	.82	6500	0.001089	32 700	2.63	9.08	116 600	176 540	0.661	0.000389	1740	1100	1663	0.63	0.96	135
170	1210	147.4	2	.49	.49	.393	2500	.000083	6350	.325	.001044	31 300	42 520	.74	6000	.000887	26 600	2.80	9.02	94 200	164 540	.573	.000346	1550	840	1465	.54	.95	128
Average									6580	.333	.001111	33 300		.78								.617				.59	.96	132
180	1220	149.0	II	.74	.74	.589	3000	.000115	9820	.380	.001226	36 800	42 700	.86	9000	.001053	31 600	3.05	8.93	166 200	236 705	.702	.000462	2020	1375	1960	.68	.97	122
181	1220	148.9	3	.74	.74	.589	2000	.000063	10 780	.425	.001303	39 100	41 320	.95	10 000	.001178	35 300	3.01	8.95	186 100	260 705	.714	.000508	2190	1555	2180	.71	1.00	133
182	1230	150.3	II	.74	.74	.589	3000	.000118	10 000	.405	.001241	37 200	43 730	.85	10 000	.001241	37 200	3.01	8.95	196 100	260 870	.752	.000533	2290	1640	2180	.72	.95	133
Average									10 200	.403	.001257	37 700		.89								.723				.70	.97	129
192	1190	146.5	4	.98	.98	.785	3500	.000126	12 360	.425	.001280	38 400	42 570	.90	12 000	.001181	35 400	3.47	8.79	244 400	308 210	.793	.000627	2620	1805	2275	.69	.87	120
193	1210	149.5	4	.98	.98	.785	3000	.000112	12 500	.425	.001210	36 300	41 350	.88	12 000	.001089	32 700	3.76	8.68	222 900	308 540	.723	.000656	2730	1535	2125	.56	.78	121
194	1210	145.6	4	.98	.98	.785	4000	.000126	12 530	.415	.001313	39 400	42 800	.92	12 000	.001173	35 200	3.20	8.88	245 500	308 540	.796	.000551	2350	1945	2445	.83	1.04	119
Average									12 460	.422	.001268	38 000		.90								.771				.69	.90	120
204	1210	145.2	5	1.23	1.11	.982	3000	.000099	13 550	.445	.001267	38 000	41 380	.92	13 000	.001138	34 100	3.49	8.78	251 500	332 540	.756	.000610	2570	1960	2595	.76	1.01	121
205	1240	150.3	5	1.23	1.11	.982	3000	.000116	14 730	.540	.001684	50 500	42 700	1.18	13 000	.001137	34 100	3.39	8.81	252 600	333 035	.759	.000583	2470	2020	2660	.82	1.08	120
206	1210	146.2	5	1.23	1.11	.982	4000	.000135	14 540	.480	.001393	41 800	41 340	1.01	14 000	.001258	37 700	3.42	8.80	278 900	356 540	.782	.000655	2730	2215	2835	.81	1.04	129
Average									14 270	.488	.001448	43 400		1.04								.766				.80	1.04	123
216	1220	147.6	6	1.47	1.30	1.178	3000	.000086	16 000	.480	.001292	38 800	41 680	.93	15 000	.001077	32 300	3.97	8.61	265 400	380 705	.697	.000708	2920	1890	2710	.65	.93	124
217	1230	146.8	II	1.47	1.30	1.178	4000	.000124	16 350	.470	.001224	36 700	41 930	.88	16 000	.001171	35 100	3.75	8.69	292 700	404 870	.723	.000703	2900	2185	3020	.75	1.04	129
218	1240	150.3	6	1.47	1.30	1.178	3000	.000098	16 300	.480	.001337	40 100	41 420	.97	16 000	.001251	37 500	3.63	8.73	315 000	405 035	.778	.000712	2930	2415	3105	.82	1.06	128
Average									16 220	.477	.001284	38 500		.93								.733				.74	1.01	127
231	1240	148.7	7	1.72	1.54	1.375	4000	.000113	18 980	.475	.001309	39 300	40 960	.96	18 000	.001226	36 800	3.79	8.67	368 600	453 035	.814	.000746	3050	2695	3310	.88	1.09	120
232	1240	147.6	7	1.72	1.54	1.375	4000	.000119	19 570	.511	.001436	43 100	40 450	1.07	19 000	.001313	39 400	3.78	8.68	395 100	477 035	.828	.000798	3220	2890	3490	.90	1.08	126
233	1240	150.3	7	1.72	1.54	1.375	4000	.000112	19 480	.520	.001474	44 200	40 610	1.09	18 000	.001168	35 000	3.94	8.62	347 500	453 035	.767	.000759	3100	2455	3200	.79	1.03	121
Average									19 340	.502	.001406	42 200		1.04								.803				.86	1.07	122
240	1240	147.9	8	1.96	1.72	1.571	4000	.000107	21 620	.550	.001438	43 100	42 170	1.02	20 000	.001219	36 600	4.13	8.55	396 500	501 035	.791	.000856	3370	2730	3450	.81	1.02	123
242	1240	148.3	II	1.96	1.72	1.571	4000	.000105	22 480	.580	.001619	48 600	42 400	1.15	21 000	.001284	38 500	4.16	9.54	416 400	525 035	.793	.000913	3540	2850	3595	.81	1.02	129
Average									22 050	.565	.001529	45 900		1.09								.792				.81	1.02	126
Grand Ave.		148.2					3300	.000107																			1.00	125

Remarks.—Average bond stress developed in beam = 125 pounds per square inch. Average ultimate bond stress from bond test pieces = 791 pounds per square inch. Ratio = 6.3.

Table 9.—Granite Concrete Proportions, 1:2:4. Age, 52 Weeks

171	1190	144.3	2	0.49	0.49	.393	3000	0.000092	7300	0.345	0.001347	40 400	42 480	0.95	7000	.001144	34 300	2.50	9.12	122 900	188 200	0.653	0.000383	1850	1210	1855	0.65	1.00	143
172	1190	145.8	2	.49	.49	.393	3000	.000095	7000	.305	.001055	31 700	42 480	.75	7000	.001055	31 700	2.83	9.01	112 200	188 200	.596	.000415	1970	990	1660	.50	.84	145
173	1210	147.3	2	.49	.49	.393	3000	.000116	7200	.345	.001104	33 100	42 760	.77	7000	.001067	32 000	2.84	9.01	113 200	188 550	.600	.000424	2010	995	1660	.50	.83	145
Average									7170	.332	.001169	35 100		.82								.616				.55	.89	144
183	1210	146.6	3	.74	.74	.589	2000	.000075	10 750	.430	.001573	47 200	43 000	1.10	10 000	.001313	39 400	2.86	9.00	208 900	260 550	.802	.000526	2430	1825	2275	.75	.94	132
184	1210	147.5	3	.74	.74	.589	2000	.000076	10 000	.375	.001280	38 400	42 190	.91	9 000	.001065	32 000	3.16	8.89	167 600	236 550	.709	.000493	2310	1340	1890	.58	.82	122
185	1220	146.1	3	.74	.74	.589	2000	.000063	10 670	(.385)	.001115	33 500	40 910	.82	10 000	.001014	30 400	3.14	8.90	159 400	260 700	.611	.000464	2190	1285	2105	.59	.96	134
Average									10 470	.397	.001323	39 700		.94								.707				.64	.91	129
195	1180	142.1	4	.98	.98	.785	3000	.000089	13 670	.445	.001217	36 500	42 560	.86	13 000	.001135	34 100	3.51	8.77	234 700	332 050	.707	.000613	2800	1715	2425	.61	.87	129
196	1220	146.9	4	.98	.98	.785	4000	.000127	13 000	.390	.001214	36 400	42 170	.86	13 000	.001214	36 400	3.35	8.83	252 400	332 700	.759	.000612	2800	1920	2530	.69	.90	128
197	1220	148.3	4	.98	.98	.785	3000	.000095	13 100	.415	(.001200)	(36 000)	42 230	.85	13 000	.001178	35 300	3.39	8.81	244 300	332 700	.734	.000605	2760	1840	2505	.67	.91	129
Average									13 260	.417	.001210	36 300		.86								.733				.66	.89	129
207	1220	147.3	5	1.23	1.11	.982	4000	.000140	14 500	.430	.001472	44 200	41 040	1.08	14 000	.001253	37 600	3.52	8.77	276 900	356 700	.776	.000680	3060	2140	2760	.70	.90	129
208	1230	149.0	5	1.23	1.11	.982	3000	.000095	15 770	.500	.001518	45 500	41 910	1.09	15 000	.001291	38 700	3.66	8.72	282 500	380 850	.742	.000745	3300	2115	2850	.64	.86	139
209	1240	148.6	5	1.23	1.11	.982	3000	.000100	15 380	.465	.001379	41 400	42 090	.98	15 000	.001318	39 500	3.42	8.80	292 200	381 050	.767	.000685	3090	2320	3025	.75	.98	137
Average									15 220	.465	.001456	43 700		1.05								.762				.70	.91	135
219	1240	147.1	6	1.47	1.30	1.178	3000	.000092	17 700	.530	.001639	49 200	41 800	1.18	16 000	.001338	40 100	3.52	8.77	339 300	405 050	.838	.000727	3230	2670	3185	.83	.99	127
220	1230	145.8	6	1.47	1.30	1.178	3000	.000097	16 600	.535	.001749	52 500	41 360	1.27	16 000	.001248	37 400	3.61	8.73	314 100	404 900	.776	.000715	3190	2405	3100	.75	.97	128
221	1240	147.3	6	1.47	1.30	1.178	3000	.000103	17 660	.470	.001438	43 100	42 900	1.00	17 000	.001350	40 500	3.56	8.75	341 500	429 100	.796	.000746	3300	2665	3350	.81	1.02	135
Average									17 320	.512	.001609	48 300		1.15								.803				.80	.99	130
228	1240	148.9	7	1.72	1.54	1.375	4000	.000146	20 650	.560	.001644	49 300	40 950	1.20	19 000	.001320	39 600	3.91	8.63	393 800	477 050	.826	.000846	3650	2800	3390	.77	.93	127
229	1240	147.6	7	1.72	1.54	1.375	3000	.000092	20 750	.545	.001585	47 600	40 610	1.17	20 000	.001388	41 600	3.99	8.60	411 500	501 100	.821	.000893	3810	2880	3510	.76	.92	134
230	1240	148.2	7	1.72	1.54	1.375	4000	.000136	21 000	.535	.001521	45 600	40 430	1.13	19 000	.001331	39 900	3.69	8.71	402 100	477 600	.842	.000781	3430	3005	3570	(.86)	1.04	126
Average									20 800	.547	.001583	47 500		1.17								.830				.80	.96	129
234	1240	149.3	8	1.96	1.72	1.571	3000	.000116	21 000	.550	.001607	48 200	41 460	1.16	20 000	.001424	42 700	3.96	8.61	468 100	501 050	.934	.000932	3920	3340	3575	.85	.91	121
235	1240	148.2	8	1.96	1.72	1.571	3000	.000096	22 100	.620	.001648	49 400	42 440	1.16	21 000	.001390	41 700	4.14	8.55	451 800	525 050	.860	.000980	4060	3105	3010	.77	.89	128
236	1240	148.2	8	1.96	1.72	1.571	3000	.000100	22 000	.605	.001790	53 700	41 730	1.29	20 000	.001291	38 700	4.11	8.56	420 100	501 050	.838	.000901	3830	2905	3465	.76	.90	122
Average									21 700	.592	.001682	50 400		1.20								.877				.79	.90	124
Grand Av		147.2					3100	.000102																			.93	131

Remarks.—Average bond stress developed in beams = 131 pounds per square inch. Average ultimate bond stress from bond test pieces = 75 pounds per square inch. Ratio = 5.9.

Note.—Values in parentheses are estimated.

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Table 10.—Limestone Concrete. Proportions, 1:2:4. Age, 4 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D−.35KD in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_2 \div C_3$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
255	1200	146.5	2	0.49	0.49	.393	2000	0.000103	5850	0.355	(0.001107)	(33 200)	42 350	0.78	5500	0.001030	30 900	3.17	8.89	108 000	152 500	0.71	0.000478	[1]1100	860	1210	0.58	0.82	120
256	1200	149.3	2	.49	.49	.393	2000	.000114	6350	.405	(.001321)	(39 600)	41 200	.96	6000	.001239	37 200	3.01	8.95	131 000	164 500	.80	.000535	1590	1090	1365	.69	.86	128
257	1200	148.3	2	.49	.49	.393	2000	.000082	5900	.350	(.001111)	(33 300)	41 410	.80	5500	.000973	29 200	3.28	8.85	101 500	152 500	.67	.000475	1470	785	1170	.53	.80	126
Average									6030	.370	(.001180)	(35 400)		.85								.73				.60	.83	123
261	1230	147.1	3	.74	.74	.589	2000	.000093	9420	.425	(.001233)	(37 000)	40 720	.91	9000	.001169	35 100	3.34	8.83	182 500	237 000	.77	.000586	1660	1395	1810	.84	1.09	123
262	1220	147.5	3	.74	.74	.589	3000	.000145	9320	.420	(.001451)	(43 500	41 080	1.06	9000	.001376	41 300	3.05	8.93	217 500	237 000	.92	.000605	1690	1795	1950	1.06	1.15	121
263	1230	145.4	3	.74	.74	.589	3500	.000163	8470	.385	(.001314)	(39 400)	41 330	.95	8000	.001162	34 900	3.05	8.93	183 500	213 000	.86	.000511	1540	1515	1760	.98	1.14	110
Average									9070	.410	(.001333)	(40 000)		.97								.85				.96	1.13	118
273	1230	146.9	4	.98	.98	.785	3000	.000141	11 300	.435	(.001381)	(41 400)	40 740	1.02	11 000	.001251	37 500	3.57	8.75	258 000	285 000	.91	.000693	1810	1855	2040	1.02	1.13	111
274	1230	144.7	4	.98	.98	.785	3000	.000133	10 800	.350	(.001269)	(38 100)	40 280	.95	10 000	.001087	32 600	3.53	8.76	224 500	261 000	.86	.000593	1680	1630	1895	.97	1.13	102
275	1240	148.3	4	.98	.98	.785	3000	.000124	11 500	.400	(.001306)	(39 200)	41 370	.95	11 000	.001214	36 400	3.60	8.74	250 000	285 000	.88	.000682	1800	1785	[1]2000	.99	1.13	111
Average									11 200	.395	(.001319)	(39 600)		.97								.88				.99	1.13	108
285	1220	147.0	5	1.23	1.11	.982	3000	.000117	13 000	.445	.001400	42 000	42 550	.99	13 000	.001400	42 000	3.65	8.72	306 500	332 500	.92	.000803	1890	2300	2500	1.22	1.32	122
286	1230	147.6	5	1.23	1.11	.982	3500	.000128	13 670	.510	(.001375)	(41 300)	41 850	.99	13 000	.001256	37 700	3.78	8.68	273 500	333 000	.82	.000764	1860	1990	2425	1.07	1.30	123
287	1240	144.4	5	1.23	1.11	.982	3000	.000123	13 100	.500	(.001504)	(45 100)	41 030	1.10	13 000	.001348	40 400	3.76	8.68	293 000	333 000	.88	.000812	1890	2145	2440	1.13	1.29	123
Average									13 260	.485	(.001426)	(42 800)		1.03								.87				1.14	1.30	123
297	1220	144.4	6	1.47	1.30	1.178	3000	.000145	14 860	.525	(.001527)	(45 800)	40 330	1.14	14 000	.001373	41 200	3.97	8.61	338 500	356 500	.95	.000903	[1]2040	2410	2535	1.18	1.24	116
298	1240	151.2	6	1.47	1.30	1.178	3000	.000119	15 520	.560	(.001560)	(46 800)	40 790	1.15	14 000	.001307	39 200	4.18	8.54	318 000	357 000	.89	.000937	[1]2070	2165	2435	1.05	1.18	117
299	1220	144.5	6	1.47	1.30	1.178	3000	.000133	15 100	.585	(.001615)	(48 500)	40 660	1.19	13 000	.001176	35 300	4.27	8.51	284 500	332 500	.85	.000878	2020	1905	2240	.94	1.11	110
Average									15 160	.557	(.001567)	(47 000)		1.16								.90				1.06	1.18	114
318	1240	146.8	7	1.72	1.54	1.375	3000	.000125	17 650	.595	(.001566)	(47 000)	42 620	1.10	16 000	.001294	38 800	4.59	8.39	369 500	405 000	.91	.001099	[1]2200	2305	2535	1.05	1.15	113
319	1240	149.5	7	1.72	1.54	1.375	3000	.000121	17 000	.560	(.001570)	(47 100)	39 740	1.19	15 000	.001168	35 000	4.55	8.41	334 500	381 000	.88	.000976	[1]2100	2100	2385	1.00	1.14	106
320	1230	147.1	7	1.72	1.54	1.375	3000	.000143	16 600	.590	(.001713)	(51 400)	40 900	1.26	15 000	.001270	38 100	4.47	8.44	366 000	381 000	.96	.001026	[1]2150	2330	2425	1.08	1.13	106
Average									17 080	.582	(.001616)	(48 500)		1.18								.92				1.04	1.14	108
321	1240	147.8	8	1.96	1.72	1.571	3000	.000128	18 870	.620	(.001808)	(54 200)	39 210	1.38	17 000	.001291	38 700	4.63	8.38	405 500	429 000	.95	.001114	[1]2210	2545	2680	1.15	1.21	109
322	1230	148.0	8	1.96	1.72	1.571	3000	.000130	18 320	.625	(.001549)	(46 500)	37 140	1.25	17 000	.001272	38 200	4.64	8.38	400 000	429 000	.93	.001103	[1]2200	[1]2500	2690	1.14	1.22	109
323	1230	145.9	8	1.96	1.72	1.571	3000	.000130	18 960	.595	(.001635)	(49 100)	37 760	1.30	18 000	.001337	40 100	4.68	8.36	418 500	453 000	.92	.001177	[1]2260	[1]2500	2825	1.15	1.25	115
Average									18 720	.613	(.001664)	(49 900)		1.31								.93				1.15	1.23	111
Grand Ave		147.1					2900	.000126																			1.13	115

[1] Value taken from curve produced

Remarks.—Average bond stress developed in beams=115 pounds per square inch. Average ultimate bond stress from bond test pieces=388 pounds per square inch. Ratio=3.4

Note.—Values in parentheses are estimated.

Table 11.—Limestone Concrete. Proportions, 1:2:4. Age, 13 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D−.35KD in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_2 \div C_3$	Unit Bond Stress, lbs. per sq. in.
249	1180	143.7	2	0.49	0.49	0.393	3000	0.000128	6000	0.305	0.000997	29 900	41 800	0.72	6000	0.000997	29 900	3.06	8.93	104 900	164 000	0.64	0.000440	1620	865	1350	0.53	[1]0.83	128
250	1190	145.0	2	.49	.49	.393	3000	.000113	6450	.350	.001091	32 700	41 350	.79	6000	.000979	29 400	2.92	8.98	103 700	164 200	.63	.000404	1500	890	1415	.59	.94	128
251	1210	148.8	2	.49	.49	.393	3000	.000111	6000	.290	.000973	29 200	40 740	.72	6000	.000973	29 200	2.73	9.04	103 700	164 500	.63	.000366	1360	945	[1]1500	.69	1.10	127
Average									6150	.315	.001021	30 600		.74								.63				.60	.96	128
264	1220	149.0	3	.74	.74	.589	3000	.000118	8780	.385	.001403	42 100	42 980	.98	8500	.001183	35 500	2.98	8.96	187 400	224 700	.83	.000503	1820	1580	1905	.87	1.05	115
265	1210	147.9	3	.74	.74	.589	3000	.000122	8500	.335	.001101	33 000	42 160	.78	8000	.000988	29 600	3.20	8.88	154 800	212 500	.73	.000466	1700	1225	[1]1500	.72	[1]0.88	110
266	1210	148.7	3	.74	.74	.589	3500	.000135	8630	.390	.001246	37 400	40 040	.93	8000	.001043	31 300	3.19	8.88	163 700	212 500	.77	.000489	1770	1300	1690	.73	.95	110
Average									8640	.370	.001250	37 500		.90								.78				.77	[1]1.00	112
276	1200	147.5	4	.98	.98	.785	3000	.000096	11 930	(.427)	.001168	35 000	41 500	.84	11 000	.001050	31 500	3.61	8.74	216 200	284 400	.76	.000593	2080	1540	2025	.74	.97	111
277	1210	145.3	4	.98	.98	.785	3000	.000143	12 000	.410	.001297	38 900	42 020	.93	12 000	.001297	38 900	3.27	8.86	270 700	308 500	.88	.000629	2180	2100	2385	.96	1.09	119
278	1210	147.3	4	.98	.98	.785	4000	.000150	11 170	.415	.001202	36 100	40 540	.89	11 000	.001138	34 100	3.48	8.78	235 500	284 500	.83	.000607	2110	1730	2085	.82	.99	111
Average									11 700	.417	.001222	36 700		.89								.82				.84	1.02	114
288	1210	146.2	5	1.23	1.11	.982	4000	.000132	13 850	.460	.001397	41 900	40 000	1.05	13 000	.001262	37 900	3.75	8.69	275 300	332 500	.83	.000756	2490	2020	2435	.81	.98	122
289	1230	149.6	5	1.23	1.11	.982	4000	.000146	12 800	.470	.001542	46 300	40 150	1.15	12 000	.001221	36 600	3.57	8.75	268 600	308 900	.87	.000678	2300	2055	2360	.89	1.03	113
290	1240	149.3	5	1.23	1.11	.982	4000	.000141	13 140	.445	.001352	40 600	40 280	1.01	13 000	.001320	39 600	3.59	8 74	290 200	333 000	.87	.000739	2450	2210	2540	.90	1.04	122
Average									13 260	.458	.001430	42 900		1.07								.86				.87	1.02	119
300	1210	146.0	6	1.47	1.30	1.178	4000	.000148	15 700	.545	.001644	49 300	40 050	1.23	14 000	.001193	35 800	3.91	8.63	295 300	356 500	.83	.000766	2510	2130	2565	.85	1.02	115
301	1220	146.0	6	1.47	1.30	1.178	4000	.000143	14 900	.490	.001557	46 700	40 740	1.15	14 500	.001282	38 500	3.89	8.64	318 200	368 700	.86	.000816	2630	2300	2675	.87	1.02	119
302	1210	147.3	6	1.47	1.30	1.178	4000	.000143	14 800	.480	.001426	42 800	40 570	1.05	14 000	.001142	34 300	4.10	8.57	279 700	356 500	.78	.000794	2590	[1]2355	2480	.75	.96	117
Average									15 130	.505	.001542	46 300		1.14								.82				.82	1.00	117
312	1240	148.2	7	1.72	1.54	1.375	4000	.000141	18 000	.500	.001487	44 600	41 120	1.08	17 000	.001268	38 000	4.10	8.57	373 800	429 000	.87	.000880	2780	2555	2935	.92	1.06	116
313	1260	151.0	7	1.72	1.54	1.375	4000	.000150	18 420	.500	.001345	40 400	40 070	1.01	18 000	.001272	38 200	4.18	8.54	373 700	453 400	.82	.000914	2850	2515	3065	.88	1.08	123
314	1220	146.0	7	1.72	1.54	1.375	4000	.000131	17 770	.500	.001325	39 800	40 440	.98	17 770	.001325	39 800	4.15	8.55	390 200	447 200	.87	.000940	2900	[1]2640	3030	.87	1.04	121
Average									18 060	.500	.001386	41 600		1.02								.85				.89	1.06	120
324	1220	146.3	8	1.96	1.72	1.571	4000	.000135	21 360	.600	.001603	48 100	37 250	1.29	21 000	.001419	42 600	4.37	8.47	454 500	524 700	.87	.001102	3200	2990	[1]3335	.93	1.07	130
325	1250	146.3	8	1.96	1.72	1.571	4000	.000134	20 730	.590	.001528	45 800	37 730	1.21	20 000	.001325	39 800	4.28	8.50	427 200	501 200	.85	.000990	3000	2855	[1]3260	.95	1.12	124
326	1230	147.3	8	1.96	1.72	1.571	4000	.000132	19 920	.550	.001564	46 900	36 830	1.27	18 000	.001212	36 400	4.36	8.47	388 400	452 900	.86	.000939	2900	2560	2975	.88	1.03	113
Average									20 670	.580	.001565	46 900		1.26								.86				.92	1.07	122
Grand Ave		146.9					3600	.000132																			1.01	119

Remarks.—Average bond stress developed in beam=119 pounds per square inch. Average ultimate bond stress from bond test pieces=466 pounds per square inch. Ratio=3.9

Note.—Values in parentheses are estimated.

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Table 12.—Limestone Concrete. Proportions, 1:2:4. Age, 26 Weeks

Beam Number	Total Weight of Beam, in lbs.	Reinforcement: Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of Beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Steel, Stress in lbs. per sq. in.	KD, in inches	D-35 KD, in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve.	C_2 from Resisting Moment.	C_3 from Bending Moment.	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
252	1190	146.9	2	0.49	0.49	0.393	[illegible]	0.000106	6310	0.335	0.001065	32 000	40 750	0.79	6000	0.000889	26 700	3.03	8.94	93 700	164 200	0.57	0.000387	1610	780	1370	0.48	0.85	128
253	1200	146.4	2	.49	.49	.393	3000	.000099	6000	.290	.000923	27 700	41 650	.67	6000	.000923	27 700	2.95	8.97	97 600	164 400	.59	.000385	1610	830	1405	.52	.87	[illegible]
254	1200	142.6	2	.49	.49	.393	2000	.000076	6000	.285	.001001	30 000	40 290	.74	6000	.001001	30 000	2.64	9.08	107 000	164 400	.65	.000359	1520	1005	1545	.66	1.02	127
Average									6100	.303	.000996	29 900		.73								.60					.55	.91	128
267	1220	147.9	[illegible]	.74	.74	.589	3500	.000117	9110	.380	.001356	40 700	40 680	1.00	9000	.001251	37 500	2.86	9.00	198 800	236 700	.84	.000502	2010	1740	2070	.87	1.03	121
268	1210	146.1	[illegible]	.74	.74	.589	4000	.000134	9000	.350	.001072	32 200	40 750	.79	9000	.001072	32 200	3.03	8.94	169 600	236 500	.72	.000467	1890	1410	1960	.75	1.04	121
269	1210	146.5	3	.74	.74	.589	3000	.000084	10 270	.420	.001284	38 500	40 710	.95	10 000	.001255	37 700	3.03	8.94	198 500	260 500	.76	.000545	2160	1650	2170	.76	1.00	133
Average									9460	.383	.001237	37 100		.91								.77					.79	1.02	125
279	1200	146.9	4	.98	.98	.785	3000	.000094	12 380	.435	.001325	39 800	41 040	.97	12 000	.001248	37 400	3.25	8.86	260 300	308 400	.84	.000602	2340	2035	2425	.87	1.04	119
280	1220	147.0	4	.98	.98	.785	4000	.000120	11 430	.415	.001268	38 000	40 990	.93	11 000	.001115	33 500	3.21	8.88	233 600	284 700	.82	.000526	2100	1845	2250	.88	1.07	110
281	1200	145.6	4	.98	.98	.785	3500	.000094	11 740	.425	.001215	36 500	41 090	.89	11 000	.001022	30 700	3.49	8.78	211 700	284 400	.74	.000549	2180	1555	2100	.71	.96	111
Average									11 850	.425	.001269	38 100		.93								.80					.82	1.02	113
291	1220	146.5	5	1.23	1.11	.982	4000	.000116	13 220	.460	.001504	45 100	39 800	1.13	13 000	.001277	38 300	3.27	8.86	285 900	332 700	.86	.000621	2400	2355	2740	.98	1.14	119
292	1230	147.5	[illegible]	1.23	1.11	.982	4000	.000132	13 000	.415	.001296	38 900	39 990	.97	12 000	.001058	31 700	3.55	8.76	232 900	308 900	.75	.000583	2280	1790	2385	.79	1.05	113
293	1240	148.7	5	1.23	1.11	.982	4000	.000114	13 600	.475	.001315	39 500	40 300	.98	13 000	.001147	34 400	3.61	8.74	251 900	333 000	.76	.000649	2480	1910	2515	.77	1.01	122
Average									13 270	.450	.001372	41 200		1.03								.79					.85	1.07	118
303	1200	143.5	6	1.47	1.30	1.178	4000	.000115	15 820	.490	.001549	46 500	41 890	1.11	15 000	.001274	38 200	3.45	8.79	324 300	380 400	.85	.000671	2540	2600	3060	1.02	1.20	119
304	1200	143.4	6	1.47	1.30	1.178	4000	.000133	15 710	.490	.001564	46 900	41 350	1.13	15 000	.001285	38 600	3.53	8.76	326 000	380 400	.86	.000702	2630	2565	2985	.98	1.13	120
305	1230	145.9	[illegible]	1.47	1.30	1.178	4000	.000123	16 930	.510	.001503	45 100	41 060	1.10	16 000	.001294	38 800	3.62	8.73	326 000	404 900	.81	.000736	2710	2505	3095	.92	1.14	129
Average									16 150	.497	.001539	46 200		1.11								.84					.97	1.16	122
315	1230	146.2	[illegible]	1.72	1.54	1.375	4000	.000121	18 940	.505	.001470	44 100	39 600	1.11	18 000	.001260	37 800	3.94	8.62	375 300	452 900	.89	.000820	2920	2655	2985	.91	1.02	121
316	1240	144.9	7	1.72	1.54	1.375	4000	.000106	18 880	.535	.001561	46 800	37 530	1.25	18 000	.001262	37 900	3.97	8.61	375 500	453 000	.89	.000831	2940	2635	2960	.90	1.01	121
317	1250	147.7	7	1.72	1.54	1.375	5000	.000159	18 000	.465	.001309	39 300	39 870	.99	18 000	.001309	39 300	3.82	8.66	392 800	453 200	.87	.000809	2900	2850	3275	.98	1.13	120
Average									18 610	.502	.001447	43 400		1.12								.88					.93	1.05	121
327	1220	144.1	[illegible]	1.96	1.72	1.571	4000	.000132	20 000	.520	.001597	47 900	36 730	1.30	18 000	.001250	37 500	4.04	8.59	409 200	452 700	.90	.000847	2980	2870	3190	[illegible]	1.07	110
328	1220	144.0	[illegible]	1.96	1.72	1.571	4000	.000127	20 420	.585	.001656	49 700	37 140	1.34	19 000	.001267	38 000	4.22	8.52	409 300	476 700	.86	.000923	3150	2770	3220	[illegible]	1.02	117
[illegible]									20 210	.553	.001627	48 800		1.32								.88					.92	1.05	114
Average																													
Grand Ave		145.9					3500	.000115																				1.04	120

[1] Sent to Jamestown.

Remarks.—Average bond stress developed in beam = 120 pounds per square inch. Average ultimate bond stress from bond test pieces = 604 pounds per square inch. Ratio = 5.0.

Table 13.—Limestone Concrete. Proportions, 1:2:4. Age, 52 Weeks

246	1200	146.1	2	0.49	0.49	0.393	3000	0.000107	7000	0.350	0.001253	37 600	41 100	0.91	6000	0.000696	20 900	3.37	8.82	72 400	164 350	0.441	0.000353	1630	550	1245	0.34	0.76	130
247	1200	144.1	2	.49	.49	.393	2000	.000070	6800	.355	.001256	37 700	41 230	.91	6000	.001005	30 200	2.72	9.05	107 300	164 350	.653	.000375	1710	980	1500	.57	.88	127
248	1210	148.3	[illegible]	.49	.49	.393	3000	.000077	6380	.320	[1].000868	26 000	40 680	.64	6000	.000800	24 000	2.96	8.96	84 400	164 500	.513	.000336	1540	715	1395	.46	.91	128
Average									6730	.342	.001255	33 800		.82								.536					.46	.85	128
270	1230	147.6	[illegible]	.74	.74	.589	3000	.000081	9360	.375	.001258	37 700	41 900	.90	9000	.001156	34 700	2.58	9.10	186 000	236 860	.785	.000403	1820	1785	2275	.98	1.25	119
271	1220	145.7	3	.74	.74	.589	3000	.000082	9000	.340	[1].000815	24 500	41 890	.58	[illegible]	.000815	24 500	3.09	8.92	128 800	236 700	.544	.000365	[illegible]	1050	1930	.63	1.15	122
272	1230	146.8	3	.74	.74	.589	3000	.000112	9700	.380	.001115	33 500	41 660	.80	9000	.000974	29 200	2.69	9.06	155 900	236 850	.658	.000357	1640	1440	2190	[illegible]	1.34	120
Average									9350	.365	.001187	31 900		.76								.662					.83	1.25	120
282	1230	147.1	4	.98	.98	.785	3000	.000097	12 000	.380	.001205	36 200	41 040	.88	12 000	.001205	36 200	3.00	8.95	254 500	308 850	.824	.000517	2230	2130	2585	.96	1.16	118
283	1230	145.9	4	.98	.98	.785	3000	.000088	12 620	.440	.001303	39 100	40 990	.95	12 000	.001162	34 900	3.22	8.87	243 200	308 850	.787	.000553	2360	1915	2435	.81	1.03	119
284	1220	147.7	4	.98	.98	.785	3000	.000107	12 200	.435	.001308	39 200	42 210	.93	12 000	.001198	35 900	3.14	8.90	250 900	308 700	.813	.000547	2330	2020	2485	.87	1.07	[illegible]
Average									12 270	.418	.001272	38 200		.92								.808					.88	1.09	118
294	1220	145.3	5	1.23	1.11	.982	3000	.000092	14 670	.470	.001487	44 600	39 720	1.12	14 000	.001368	41 000	3.22	8.87	306 700	356 700	.860	.000651	2690	2565	2985	.95	1.11	127
295	1240	146.4	5	1.23	1.11	.982	3000	.000095	14 380	.460	.001410	42 300	40 270	1.05	14 000	.001289	38 700	3.25	8.86	289 000	357 000	.810	.000620	2590	2395	2955	.92	1.14	128
296	1240	147.1	5	1 23	1.11	.982	3000	.000097	14 100	.460	.001453	43 600	40 840	1.07	14 000	.001294	38 800	3.42	8.80	287 000	357 000	.804	.000671	2750	2275	2830	.83	1.03	129
Average									14 380	.463	.001450	43 500		1.08								.825					.90	1.09	128
306	1230	149.6	6	1.47	1.30	1.178	3000	.000104	16 450	.550	.001692	50 800	39 650	1.28	15 000	.001272	38 200	3.77	8.68	318 000	380 900	.835	.000770	3050	2365	2830	.78	.93	122
307	1250	145.6	6	1.47	1.30	1.178	3000	.000097	16 070	(.458)	(.001728)	(51 800)	40 770	1.27	15 000	.001299	39 000	3.34	8.83	333 400	381 150	.875	.000652	2690	2750	3145	1.02	1.17	119
308	1230	147.2	[illegible]	1.47	1.30	1.178	[illegible]	.000065	16 000	.460	[1].000846	[1] 25 400	40 440	[1] .63	16 000	.000846	25 400	3.18	8.89	219 300	404 900	.542	[1].000395	1790	[illegible]	[illegible]	1.05	[1] 1.94	125
Average									16 170	.489	.001710	51 300		1.28								.751					.95	1.05	122
309	1220	145.1	7	1.72	1.54	1.375	3000	.000147	18 800	.500	(.001328)	(39 800)	40 590	.98	18 000	.001254	37 600	4.00	8.60	371 900	453 850	.819	.000835	3230	2595	3170	.80	.98	122
310	1220	146.5	7	1.72	1.54	1.375	4000	.000131	19 000	.535	.001581	47 400	39 750	1.19	18 000	.001369	41 100	3.98	8.61	407 200	452 700	.900	.000904	3410	2855	3170	.84	.93	121
311	1240	146.9	[illegible]	1.72	1.54	1.375	4000	.000124	19 320	.575	(.001422)	(42 700)	40 820	1.05	19 000	.001344	40 300	4.03	8.59	398 000	478 200	.832	.000907	3420	2760	3315	.81	.97	128
Average									19 040	.537	.001444	43 300		1.07								.850					.82	.96	124
330	1230	144.6	[illegible]	1.96	1.72	1.571	4000	.000130	21 000	.555	.001574	47 200	36 790	1.28	20 000	.001403	42 100	3.85	8.65	464 800	500 850	.928	.000878	3350	3395	[illegible]	1.01	[illegible]	120
331	1250	149.5	[illegible]	1.96	1.72	1.571	4000	.000114	21 580	.530	.001432	43 000	37 510	1.15	21 000	.001374	41 200	4.16	8.54	445 700	525 200	.849	.000980	3690	3050	3595	.85	1.00	[illegible]
332	1210	145.7	[illegible]	1.96	1.72	1.571	4000	.000128	21 150	(.548)	.001588	47 600	38 720	1.23	21 000	.001422	42 700	4.14	8.55	462 700	524 500	.882	.001003	3640	3180	3170	.87	.87	128
Average									21 240	.544	.001531	45 900		1.22								.886					.91	.99	[illegible]
Grand Ave		146.6					3200	.000101																				1.04	124

[1] Not used in average.

Remarks.—Average bond stress developed in beam = 124 pounds per square inch. Average ultimate bond stress from bond test pieces = 519 pounds per square inch. Ratio = 4.2.

Note.—Values in parentheses are estimated.

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Table 14.—Gravel Concrete. Proportions, 1:2:4. Age, 4 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D−.35KD, in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1, from Cylinder Curve	C_2, from Resisting Moment	C_3, from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
333	1150	143.6	2	0.49	0.49	0.393	2000	0.000099	5800	0.325	(.001289)	(38 700)	43 500	0.89	5500	0.001104	33 100	2.77	9.03	117 500	151 600	0.78	0.000422	1780	1060	1360	0.60	0.76	117
334	1140	140.0	2	.49	.49	.393	2000	.000094	6000	.350	(.001253)	(37 600)	41 910	.90	5500	.000949	28 500	3.02	8.94	100 000	151 400	.66	.000411	1750	830	1260	.47	.72	118
335	1170	141.8	2	.49	.49	.393	2000	.000085	6610	.370	(.001194)	(35 800)	44 930	.80	6500	.001150	34 500	2.69	9.06	122 800	175 900	.70	.000424	1790	1130	1615	.63	.90	135
Average									6140	.348	(.001245)	(37 400)		.86								.71					.57	.79	123
345	1180	145.8	3	.74	.74	.589	2000	.000095	9420	.435	(.001699)	[1](51 000)	41 440	1.23	9000	.001460	43 800	2.95	8.97	231 500	236 000	.98	.000609	2300	1970	2010	.86	.87	[illegible]
346	1170	144.6	[illegible]	.74	.74	.589	2500	.000116	9000	.415	.001328	39 800	43 640	.91	8500	.001156	34 700	3.26	8.86	181 000	223 900	.81	.000560	2180	1410	1740	.65	.80	116
347	1170	144.4	3	.74	.74	.589	2500	.000109	9250	.425	(.001263)	(37 900)	43 760	.87	9000	.001185	35 550	3.34	8.83	184 900	235 900	.78	.000593	2270	1410	1810	.62	.80	122
Average									9220	.425	.001430	38 900		1.00								.86					.71	.82	119
357	1170	143.7	4	.98	.98	.785	3000	.000118	13 000	.470	.001557	46 700	43 460	1.07	12 500	.001408	42 200	3.45	8.79	291 600	319 900	.91	.000741	2610	2170	2385	.83	.91	128
358	1180	146.0	4	.98	.98	.785	3000	.000119	12 260	.465	(.001296)	(38 900)	42 410	.92	12 000	.001241	37 200	3.46	8.79	257 000	308 000	.83	.000656	2420	1900	2290	.79	.95	119
359	1190	144.6	4	.98	.98	.785	3000	.000119	12 080	.455	(.001379)	(41 400)	[2]41 930	.99	12 000	.001350	40 500	3.26	8.86	281 800	308 200	.91	.000652	2410	2200	2420	.91	1.00	119
Average									12 450	.463	.001411	42 300		.99								.88					.84	.95	122
369	1170	141.8	5	1.23	1.11	.982	2000	.000080	14 000	.500	.001497	44 900	40 270	1.11	13 000	.001308	39 200	3.81	8.67	283 900	331 900	.86	.000805	[3]2730	2060	2395	.75	[illegible]	122
370	1160	141.6	[illegible]	1.23	1.11	.982	2000	.000078	13 400	.515	(.001704)	(51 100)	39 930	1.28	12 000	.001212	36 400	3.61	8.74	266 600	307 700	.87	.000685	2490	2020	2320	.81	.93	112
371	1160	145.3	5	1.23	1.11	.982	2000	.000095	13 870	.540	.001527	45 800	39 540	1.16	13 000	.001356	40 700	3.69	8.71	296 700	331 700	.89	.000791	2710	2200	2470	.81	.91	121
Average									13 760	.518	.001576	47 300		1.18								.87					.79	.91	118
381	1180	145.7	6	1.47	1.30	1.178	3000	.000110	15 240	.565	(.001631)	(48 900)	38 010	1.29	14 000	.001234	37 000	4.11	8.56	301 300	356 000	.85	.000862	[3]2840	2080	2445	.73	.86	117
382	1190	143.6	6	1.47	1.30	1.178	3000	.000118	15 300	.555	(.001621)	(48 600)	38 570	1.26	15 000	.001392	41 800	3.85	8.65	346 100	380 200	.91	.000870	[3]2850	2530	2780	.89	.98	122
383	1200	145.2	[illegible]	1.47	1.30	1.178	3000	.000123	15 920	.520	(.001539)	(46 200)	39 170	1.18	15 000	.001362	40 900	3.65	8.72	343 000	380 400	.90	.000782	2690	2620	2910	.97	1.08	121
Average									15 490	.547	(.001597)	(47 900)		1.24								.89					.86	.97	120
393	1210	147.4	7	1.72	1.54	1.375	3000	.000105	17 510	.535	.001391	41 700	39 680	1.05	17 000	.001326	39 800	4.11	8.56	390 900	428 500	.91	.000927	[3]2940	2670	2935	.91	1.00	116
394	1190	145.5	7	1.72	1.54	1.375	3000	.000117	18 240	.585	(.001626)	(48 800)	39 120	1.25	17 000	.001402	42 100	4.06	8.58	414 900	428 200	.97	.000959	[3]2980	2860	2950	.96	.99	115
395	1200	143.4	7	1.72	1.54	1.375	3000	.000107	17 920	.530	(.001706)	(51 200)	40 030	1.28	17 000	.001344	40 300	3.93	8.62	400 200	428 400	.93	.000872	[3]2850	2840	3055	1.00	1.07	115
Average									17 890	.550	.001574	47 200		1.19								.94					.96	1.02	115
405	1200	146.3	8	1.96	1.72	1.571	3000	.000093	19 950	.580	.001617	48 500	38 630	1.26	18 000	.001214	36 400	4.45	8.44	386 100	452 400	.85	.000975	[3]3000	2500	2940	.83	.98	113
406	1220	147.8	8	1.96	1.72	1.571	3000	.000105	19 800	.585	.001783	53 500	38 680	1.38	19 000	.001393	41 800	4.11	8.56	453 700	476 800	.95	.000974	[3]3000	3140	3305	1.05	1.10	116
407	1210	147.3	[illegible]	1.96	1.72	1.571	2000	.000071	20 450	.630	.001788	53 600	38 590	1.39	19 000	.001366	41 000	4.18	8.53	443 300	476 500	.93	.000979	[3]3000	3020	3245	1.01	1.08	117
Average									20 070	.598	.001729	51 900		1.34								.91					.96	1.05	115
Grand Ave.		144.5					2500	.000103																				.93	119

[1] Not used in average.

[2] Average of only 3 rods.

[3] Value taken from average curve produced.

Remarks.—Average bond stress developed in beam=119 pounds per square inch. Average ultimate bond stress from bond test pieces=586 pounds per square inch. Ratio=4.9.

Note.—Values in parentheses are estimated.

Table 15.—Gravel Concrete. Proportions, 1:2:4. Age, 13 Weeks

336	1170	143.7	2	0.49	0.49	0.393	2500	0.000098	7350	0.365	0.001357	40 700	42 590	0.96	7000	0.001256	37 700	2.59	9.09	134 600	187 900	0.72	0.000439	1980	1290	1790	0.65	0.90	143
337	1170	141.7	2	.49	.49	.393	2000	.000076	6740	.340	.001241	37 200	41 530	.90	6500	.001162	34 900	2.55	9.11	124 900	175 900	.71	.000398	1800	1210	1705	.67	.95	134
338	1160	142.4	[illegible]	.49	.49	.393	2000	.000077					42 370		5500	.000797	23 900	2.97	8.96	84 100	151 700	.55	.000337	1540	710	1290	.46	.84	118
Average									7050	.353	.001299	39 000		.93								.66					.59	.90	132
348	1190	147.0	3	.74	.74	.589	3000	.000105	9620	.390	.001338	40 100	42 010	.95	9000	.001072	32 200	3.10	8.92	169 000	236 200	.72	.000481	2160	1380	1915	.64	.89	121
349	1200	145.7	[illegible]	.74	.74	.589	[illegible]	.000102	11 050	.465	.001516	45 500	41 330	1.10	11 000	.001467	44 000	2.73	9.04	234 300	284 400	.82	.000551	2440	2140	2610	.88	1.07	143
350	1180	145.9	3	.74	.74	.589	3000	.000116	8800	.345	.001250	37 500	43 390	.86	8000	.000945	28 400	3.07	8.93	149 100	212 000	.70	.000418	1880	1220	1745	.65	.93	109
Average									9820	.400	.001368	41 000		.97								.75					.72	.96	124
360	1190	145.7	[illegible]	.98	.98	.785	4000	.000136	12 850	.400	.001362	40 900	43 310	.94	12 000	.001200	36 000	3.17	8.89	251 300	308 200	.82	.000556	2460	2010	2450	.82	1.00	118
361	1200	143.0	4	.98	.98	.785	3000	.000094	12 450	.390	.001309	39 300	39 830	.99	12 000	.001188	35 600	3.05	8.93	249 700	308 400	.81	.000521	2320	2060	2595	.89	1.10	118
362	1180	145.0	4	.98	.98	.785	3000	.000104	12 960	.430	.001468	44 000	40 040	1.10	12 000	.001282	38 500	3.18	8.89	268 800	308 000	.87	.000597	2610	2140	2460	.82	.94	118
Average									12 750	.407	.001380	41 400		1.01								.83					.84	1.01	118
372	1210	147.1	5	1.23	1.11	.982	3000	.000109	14 870	.470	.001385	41 600	39 510	1.05	14 000	.001248	37 400	3.48	8.78	275 800	356 500	.77	.000667	2860	2160	2805	.76	.98	130
373	1200	144.9	5	1.23	1.11	.982	3000	.000098	15 150	.505	.001376	41 300	39 900	1.04	15 000	.001361	40 800	3.48	8.78	300 900	380 400	.79	.000725	3040	2350	2975	.77	.98	137
374	1210	147.4	[illegible]	1.23	1.11	.982	[illegible]	.000112	14 550	(.482)	.001458	43 700	39 830	1.10	14 000	.001380	41 400	3.33	8.83	307 700	356 500	.86	.000690	2940	2500	2905	.85	.99	128
Average									14 860	.486	.001406	42 200		1.06								.81					.79	.98	132
384	1190	143.1	6	1.47	1.30	1.178	3000	.000103	16 840	.520	.001653	49 600	37 950	1.31	16 000	.001345	40 400	3.45	8.79	342 500	404 200	.85	.000710	3000	2750	3235	.92	1.08	127
385	1210	146.4	[illegible]	1.47	1.30	1.178	3000	.000098	16 720	.485	.001559	46 800	37 470	1.25	15 000	.001270	38 100	3.48	8.78	322 900	380 500	.85	.000678	[illegible]	2570	3025	.89	1.05	120
386	1200	145.9	[illegible]	1.47	1.30	1.178	3000	.000103	16 000	.465	.001391	41 700	38 050	1.10	15 000	.001241	37 200	3.64	8.73	312 400	380 400	.82	.000709	3000	2390	2915	.80	.97	121
Average									16 520	.490	.001534	46 000		1.22								.84					.87	1.03	123
396	1200	149.6	7	1.72	1.54	1.375	[illegible]	.000127	19 650	.535	.001602	48 100	38 080	1.26	18 630	.001359	40 800	3.73	8.69	410 000	467 500	[illegible]	.000807	3280	3040	3455	.95	1.05	123
397	1200	143.3	7	1.72	1.54	1.375	[illegible]	.000113	19 960	.555	.001718	51 500	41 020	1.26	17 100	.001231	36 900	3.66	8.72	372 500	430 800	.86	.000712	3000	2800	3255	.93	1.08	113
398	1230	148.7	7	1.72	1.54	1.375	[illegible]	.000122	19 100	.550	.001655	49 700	38 920	1.28	18 000	.001294	38 800	3.83	8.66	387 800	452 900	.86	.000803	3270	2810	3270	.86	1.00	120
Average									19 570	.547	.001658	49 800		1.27								.87					.91	1.04	119
408	1230	147.4	8	1.96	1.72	1.571	4000	.000117	22 000	.540	.001504	45 100	38 940	1.16	21 000	.001385	41 600	3.98	8.61	455 100	524 900	.87	.000915	3540	3230	3715	.91	1.05	127
409	1240	147.6	8	1.96	1.72	1.571	4000	.000118	22 350	.595	.001826	54 800	38 630	1.42	21 000	.001397	41 900	3.95	8.62	459 900	525 000	.88	.000914	3540	3280	3725	.93	1.05	127
410	1200	142.8	[illegible]	1.96	1.72	1.571	[illegible]	.000122	21 690	.575	.001610	48 300	38 110	1.27	20 000	.001349	40 500	4.00	8.60	442 900	500 400	.89	.000898	3500	3130	3515	.89	1.00	121
Average									22 010	.570	.001647	49 400		1.28								[illegible]					.91	1.03	125
Grand Ave.		145.2					3200	.000107																				.99	125

Remarks.—Average bond stress developed in beam=125 pounds per square inch. Average ultimate bond stress from bond test pieces=675 pounds per square inch. Ratio=5.4.

Note.—Values in parentheses are estimated.

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Table 16.—Gravel Concrete. Proportions, 1:2:4. Age, 26 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D. 35 KD, in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 From Cylinder Curve.	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27a	28	29	30
339	1170	143.4	2	0.49	0.49	0.393	2500	0.000087	6500	0.280	0.001127	33 800	42 160	0.80	6500	0.001127	33 800	2.60	9.09	120 700	175 900	0.69	0.000396	2030	1150	1665	0.57	0.82	134
340	1170	141.7	2	.49	.49	.393	3000	.000111	6500	.290	.001029	30 900	45 220	.68	6500	.001029	30 900	2.59	9.09	110 300	175 900	.63	.000361	1870	1060	1685	.57	.90	134
341	1170	144.3	2	.49	.49	.393	2500	.000091	6680	.320	.001212	36 400	40 700	.89	6500	.001144	34 300	2.52	9.12	122 900	175 900	.70	.000384	1980	1200	1715	.61	.87	134
Average									6560	.297	.001123	33 700		.79								.67					.88	.84	134
351	1180	143.1	3	.74	.74	.589	3500	.000110	10 000	.370	.001241	37 200	42 110	.88	10 000	.001241	37 200	2.95	8.97	196 600	260 000	.76	.000519	2570	1670	2195	.65	.85	132
352	1200	143.7	3	.74	.74	.589	3000	.000110	10 300	.380	.001220	36 600	43 960	.83	10 000	.001164	34 900	2.99	8.95	184 000	260 400	.71	.000497	2470	1550	2185	.63	.88	131
353	1180	143.9	3	.74	.74	.589	3000	.000098	9830	.360	.001078	32 300	43 140	.75	9000	.000950	28 500	3.16	8.89	149 200	236 000	.63	.000438	2220	1200	1905	.54	.86	121
Average							10 040	.370	.001180	35 400		.82										.70					.61	.86	129
363	1200	144.6	4	.98	.98	.785	3000	.000094	13 530	.445	.001429	42 900	39 400	1.09	13 000	.001299	39 000	3.10	8.91	273 200	332 400	.82	.000583	2830	2220	2705	.78	.96	127
364	1180	140.4	4	.98	.98	.785	3000	.000097	13 100	.430	.001543	46 300	40 310	1.15	12 000	.001229	36 900	2.95	8.97	260 000	308 000	.84	.000513	2550	2210	2630	.87	1.03	117
365	1190	144.5	4	.98	.98	.785	3000	.000094	13 000	.400	.001239	37 200	39 680	.94	13 000	.001239	37 200	3.22	8.87	259 200	332 200	.78	.000588	2840	2040	2615	.72	.92	127
Average							13 210	.425	.001404	42 100		1.06										.81					.79	.97	124
375	1180	141.9	5	1.23	1.11	.982	3000	.000094	15 780	.500	.001579	47 400	39 850	1.19	15 000	.001415	42 450	3.26	8.87	317 000	380 000	.83	.000683	3210	2620	3155	.82	.98	136
376	1170	139.3	5	1.23	1.11	.982	3000	.000096	14 990	.470	.001328	39 800	39 660	1.00	14 000	.001205	36 150	3.32	8.84	269 100	355 900	.76	.000599	2900	2190	2880	.76	.99	127
377	1170	140.9	5	1.23	1.11	.982	4000	.000140	15 360	.490	.001543	46 300	39 680	1.17	14 000	.001267	38 000	3.31	8.84	282 900	355 900	.79	.000627	3000	2310	2925	.79	.98	127
Average							15 380	.487	.001483	44 500		1.12										.79					.79	.98	130
387	1200	145.0	6	1.47	1.30	1.178	4000	.000122	16 880	.525	.001607	48 200	38 400	1.26	16 000	.001249	37 500	3.87	8.65	310 400	404 400	.77	.000788	3580	2260	2935	.63	.82	131
388	1190	141.4	6	1.47	1.30	1.178	4000	.000121	17 000	.485	.001516	45 500	38 120	1.19	16 000	.001340	40 200	3.37	8.82	343 000	404 200	.85	.000680	3200	2810	3305	.88	1.03	126
389	1200	144.8	6	1.47	1.30	1.178	4000	.000130	16 980	.485	.001463	43 900	38 540	1.14	16 000	.001272	38 200	3.65	8.72	320 400	404 400	.79	.000731	3380	2450	3100	.73	.92	128
Average							16 950	.498	.001529	45 900		1.20										.80					.75	.92	128
399	1200	144.0	7	1.72	1.54	1.375	4000	.000119	19 650	.495	.001496	44 900	39 050	1.15	19 000	.001338	40 100	3.82	8.66	400 800	476 400	.84	.000828	3700	2910	3465	.79	.94	126
400	1210	142.5	7	1.72	1.54	1.375	4000	.000113	20 000	.495	.001415	42 500	38 250	1.11	19 000	.001313	39 400	3.61	8.74	399 100	476 500	.84	.000741	3420	3040	3620	.89	1.06	125
401	1200	144.5	7	1.72	1.54	1.375	4000	.000124	19 880	.505	.001578	47 300	38 740	1.22	18 000	.001290	38 700	3.64	8.73	391 300	452 400	.87	.000740	3420	2960	3400	.87	.99	119
Average							19 680	.498	.001496	44 900		1.16										.85					.85	1.00	123
412	1200	141.9	8	1.96	1.72	1.571	4000	.000118	22 000	.530	.001492	44 800	38 240	1.17	21 000	.001383	41 500	3.75	8.69	461 400	524 400	.88	.000828	3700	3440	3710	.93	1.06	125
413	1220	144.7	8	1.96	1.72	1.571	4000	.000117	22 000	.555	.001550	46 500	38 620	1.20	21 000	.001316	39 500	3.81	8.67	437 500	524 700	.83	.000810	3640	3220	3880	.28	1.07	125
Average							22 000	.543	.001521	45 700		1.19										.86					.91	1.07	125
Grand Ave		143.0					3400	.000109																				.95	128

[1] Sent to Jamestown.

Remarks.– Average bond stress developed in beam=128 pounds per square inch. Average ultimate bond stress from bond test pieces=738 pounds per square inch. Ratio=5.8.

Table 17.—Gravel Concrete. Proportions, 1:2:4. Age, 52 Weeks

342	1150	142.0	2	0.49	0.49	0.393	3000	0.000107	6280	0.250	0.001091	32 700	43 870	0.75	6000	0.000872	26 200	2.71	9.05	93 100	163 550	0.569	0.000325	1760	835	1500	0.49	0.85	126
343	1150	142.5	2	.49	.49	.393	3000	.000119	5800	.265	.000773	23 200	42 520	.55	5500	.000603	18 100	3.19	8.88	63 100	151 550	.416	.000282	1560	500	1200	.32	.77	120
344	1160	144.5	2	.49	.49	.393	3000	.000123	6800	.365	.001169	35 100	46 030	.76	6500	.001111	33 300	2.75	9.04	118 200	175 700	.673	.000420	2220	1070	1590	.48	.72	135
Average							6290	.293	.001011	30 300		.69										.553					.43	.78	127
354	1160	143.3	3	.74	.74	.589	3000	.000104	9600	.370	.001456	43 700	44 280	.99	9000	.001142	34 300	3.00	8.95	180 900	235 700	.768	.000488	2560	1515	1975	.59	.77	121
355	1160	142.2	3	.74	.74	.589	3000	.000097	10 450	(.420)	.001444	43 300	42 980	1.01	10 000	.001306	39 200	2.82	9.01	208 100	259 700	.801	.000513	2690	1845	2305	.69	.86	132
356	1150	141.0	3	.74	.74	.589	3500	.000118	9950	.380	.001431	42 900	42 880	1.00	9000	.001123	33 700	2.98	8.96	177 900	235 550	.755	.000477	2500	1500	1985	.60	.79	120
Average							10 000	.390	.001444	43 300		1.00										.775					.63	.81	124
366	1170	143.0	4	.98	.98	.785	3000	.000100	13 950	.470	.001562	46 900	40 480	1.16	13 000	.001374	41 200	3.02	8.94	289 300	331 900	.872	.000596	3070	2410	2765	.79	.90	126
367	1190	144.2	4	.98	.98	.785	3000	.000098	13 870	(.435)	.001439	43 200	40 030	1.08	13 000	.001279	38 400	3.17	8.89	268 100	332 200	.807	.000595	3070	2140	2650	.70	.86	127
368	1180	144.6	4	.98	.98	.785	3500	.000092	13 890	(.451)	.001390	41 700	39 810	1.05	13 000	.001232	37 000	3.40	8.81	256 000	332 050	.771	.000535	3240	1925	2495	.59	.77	128
Average							13 900	.452	.001464	43 900		1.10										.817					.69	.84	127
378	1170	144.5	5	1.23	1.11	.982	3000	.000112	14 230	(.450)	(.001240)	(37 200)	38 090	.98	14 000	.001210	36 300	3.49	8.78	267 700	357 050	.750	.000648	3300	2080	2780	.63	.84	129
379	1180	143.8	5	1.23	1.11	.982	3000	.000106	14 850	.480	.001364	40 900	37 850	1.08	14 000	.001234	37 000	3.47	8.79	273 200	356 050	.767	.000657	3340	2140	2790	.64	.84	129
380	1160	141.9	5	1.23	1.11	.982	3000	.000106	14 000	.460	.001568	47 000	38 180	1.23	13 000	.001224	36 700	3.32	8.84	273 100	331 700	.823	.000608	3120	2220	2700	.71	.87	119
Average							14 360	.463	.001391	41 700		1.10										.780					.66	.85	126
390	1190	143.5	6	1.47	1.30	1.178	4000	.000106	16 980	(.470)	(.001190)	(35 700)	39 330	.91	16 000	.001105	33 200	3.99	8.60	272 400	405 400	.672	.000733	3650	1930	2870	.53	.79	131
391	1200	143.1	6	1.47	1.30	1.178	4000	.000114	17 440	.490	.001487	44 600	38 050	1.17	17 000	.001391	41 700	3.54	8.76	352 200	428 400	.822	.000760	3750	2760	3360	.74	.90	135
392	1190	144.3	6	1.47	1.30	1.178	4000	.000143	17 250	.525	.001668	50 000	38 510	1.30	16 000	.001309	39 300	3.57	8.75	331 400	404 250	.820	.000728	3620	2580	3145	.71	.87	128
Average							17 220	.495	.001448	43 400		1.13										.771					.66	.85	131
402	1200	144.1	7	1.72	1.54	1.375	4000	.000105	19 920	(.507)	(.001400)	(42 000)	38 580	1.09	19 000	.001295	38 900	3.89	8.64	387 500	477 500	.812	.000823	3970	2770	3410	.70	.86	127
403	1220	146.5	7	1.72	1.54	1.375	4000	.000119	19 860	(.555)	.001675	50 300	38 910	1.29	18 000	.001345	40 400	3.70	8.71	407 100	452 700	.899	.000791	3860	3035	3375	.79	.87	119
404	1200	144.3	7	1.72	1.54	1.375	4000	.000123	20 200	(.539)	.001771	53 100	38 970	1.36	19 000	.001374	41 200	3.75	8.69	413 800	476 400	.869	.000826	3990	3050	3510	.76	.88	126
Average							19 990	(.534)	.001615	48 500		1.25										.860					.75	.87	124
414	1190	143.7	8	1.96	1.72	1.571	4000	.000119	21 410	.585	.001916	57 500	38 670	1.49	20 000	.001315	39 500	3.96	8.61	433 000	500 250	.866	.000961	4110	3085	3560	.75	.87	121
415	1190	143.0	8	1.96	1.72	1.571	4000	.000112	21 440	(.516)	(.001589)	(47 700)	38 320	1.24	20 000	.001222	36 700	3.99	8.60	401 400	501 400	.801	.000810	3930	2845	3550	.72	.90	121
416	1190	143.5	8	1.96	1.72	1.571	4000	.000127	21 000	.560	.001651	49 500	38 940	1.27	20 000	.001366	41 000	3.98	8.61	449 200	500 250	.898	.000904	4240	3190	3550	.73	.84	121
Average							21 280	.554	.001719	51 600		1.33										.855					.74	.87	121
Grand Ave		143.5					3900	.000112																				.81	126

Remarks.—Average bond stress developed in beam=126 pounds per square inch. Average ultimate bond stress from bond test pieces=781 pounds per square inch. Ratio=6.2.

Note.—Values in parentheses are estimated.

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Table 18.—Cinder Concrete. Proportions 1:2:4. Age, 4 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D–35 KD, in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
417	970	120.8	2	0.49	0.49	0.393	2000	0.000195	5900	0.440	0.001169	35 100	36 960	0.95	5500	0.001009	30 300	4.06	8.58	102 100	148 600	0.69	0.000688	940	660	925	0.70	1.02	120
418	980	121.4	2	.49	.49	.393	1500	.000133	5900	.385	.001132	34 000	37 720	.90	5500	.000976	29 300	4.08	8.57	98 600	148 700	.66	.000674	930	635	960	.68	1.03	121
419	950	117.6	2	.49	.49	.393	2000	.000201	6390	.445	.001294	38 800	37 390	1.04	6000	.001205	36 200	4.11	8.56	121 700	160 300	.76	.000840	1080	780	1025	.72	.95	130
Average									6060	.423	.001198	36 000		.96								.70					.70	1.00	124
429	990	121.8	3	.74	.74	.589	2000	.000157	8700	.520	.001405	42 200	39 090	1.08	8500	.001311	39 300	4.50	8.43	195 200	220 900	.88	.001073	1240	1160	1320	.94	1.06	120
430	990	122.5	3	.74	.74	.589	2000	.000171	8760	.520	.001362	40 900	40 490	1.01	8500	.001236	37 100	4.65	8.37	182 900	220 900	.83	.001072	1240	1060	1275	.85	1.03	121
431	980	121.9	II	.74	.74	.589	2500	.000199	8940	.505	.001234	37 000	41 300	.90	8500	.001113	33 400	4.81	8.32	163 700	220 700	.74	.001032	1210	920	1245	.76	1.03	121
Average									8800	.515	.001334	40 000		1.00								.82					.85	1.04	121
441	960	119.2	4	.98	.98	.785	2000	.000166	10 500	.585	.001414	42 400	40 520	1.05	10 000	.001215	36 500	5.50	8.08	231 600	256 400	.90	.001487	1410	1175	1305	.83	.93	108
442	970	119.1	4	.98	.98	.785	2000	.000153	10 900	.595	(.001335)	(40 100)	41 840	.96	10 500	.001186	35 600	5.54	8.06	225 300	268 600	.84	.001471	1400	1135	1350	.81	.96	113
443	970	118.3	4	.98	.98	.785	3000	.000249	11 470	.625	(.001458)	(43 700)	41 150	1.06	10 000	.001060	31 800	5.43	8.10	202 300	256 600	.79	.001258	1330	1035	1310	.78	.99	[illegible]
Average									10 960	.602	.001402	(42 100)		1.02								.84					.81	.96	110
453	960	118.6	5	1.23	1.11	.982	2000	.000173	11 700	.740	.001684	50 500	40 330	1.25	11 000	.001246	37 400	5.70	8.01	238 700	280 400	.85	.001654	[1] 1460	1245	1465	.85	1.00	117
454	980	118.8	5	1.23	1.11	.982	2000	.000176	11 130	.765	.001655	49 700	38 210	1.30	10 000	.001126	33 800	5.59	8.04	217 400	256 700	.85	.001431	1390	1155	1360	.83	.98	107
455	980	119.5	5	1.23	1.11	.982	2000	.000170	11 450	.665	.001508	45 200	39 750	1.14	10 000	.001097	32 900	5.36	8.12	215 300	256 700	.84	.001268	1340	1180	1405	.88	1.05	105
Average									11 430	.723	.001616	48 500		1.23								.85					.85	1.01	110
465	970	118.1	6	1.47	1.30	1.178	2000	.000164	13 100	(.760)	(.001660)	(49 800)	36 980	1.35	12 000	.001231	36 900	5.93	7.92	260 200	304 600	.85	.001790	[1] 1500	1345	1580	.90	1.05	115
466	980	117.4	6	1.47	1.30	1.178	2000	.000157	13 460	.810	(.001906)	(57 200)	37 870	1.51	12 000	.001176	35 300	5.71	8.00	254 200	304 700	.83	.001566	[1] 1440	1350	1625	.94	1.13	113
467	980	119.6	II	1.47	1.30	1.178	2000	.000153	14 100	.845	(.001762)	(52 900)	37 350	1.42	13 500	.001318	39 500	5.67	8.02	285 800	340 700	.84	.001726	[1] 1480	1530	1820	1.03	1.23	125
Average									13 550	.805	.001776	(53 300)		1.43								.84					.96	1.14	118
477	990	119.2	7	1.72	1.54	1.375	3000	.000219	14 870	.885	.001925	57 800	36 730	1.57	13 000	.001179	35 400	5.86	7.95	306 900	328 900	.93	.001668	[1] 1460	1580	1700	1.08	1.16	101
478	980	116.4	7	1.72	1.54	1.375	3000	.000213	14 590	.870	.001701	51 000	35 790	1.42	13 000	.001198	35 900	5.82	7.96	312 000	328 700	.95	.001669	[1] 1460	1615	1760	1.11	1.16	101
479	980	117.1	7	1.72	1.54	1.375	2000	.000146	15 170	.875	(.001949)	(58 500)	37 620	1.56	13 000	.001097	32 900	5.93	7.92	283 100	328 700	.86	.001598	[1] 1440	1445	1680	1.00	1.17	102
Average									14 880	.877	.001858	(55 800)		1.52								.91					1.06	1.16	101
489	990	118.9	8	1.96	1.72	1.571	2000	.000148	15 750	.980	(.002046)	(61 400)	38 020	1.61	13 000	.001094	32 800	6.28	7.80	297 800	328 900	.91	.001844	[1] 1510	1475	1620	.98	1.07	96
490	1000	117.5	8	1.96	1.72	1.571	3000	.000219	16 000	1.005	.001974	59 200	37 690	1.57	13 000	.001055	31 700	6.09	7.87	293 700	329 100	.89	.001641	[1] 1460	1485	1670	1.02	1.14	95
491	1000	150.0	II	1.96	1.72	1.571	3000	.000208	16 410	1.000	(.001993)	(59 800)	37 950	1.58	14 000	.001145	34 400	6.06	7.88	319 600	353 100	.90	.001765	[1] 1490	1625	1805	1.09	1.21	101
Average									16 050	.995	.002004	(60 100)		1.59								.90					1.03	1.14	97
Grand Ave		119.0					2200	.000180																				1.08	111

Note.—Values in parentheses are estimated.

[1] Values taken from average curve produced.

Table 19.—Cinder Concrete. Proportions 1:2:4. Age, 13 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D–35 KD, in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
420	960	119.2	2	0.49	0.49	0.393	1000	0.000094	6120	0.395	0.001265	38 000	38 400	0.99	6000	0.001085	32 600	3.83	8.66	110 900	160 400	0.69	0.000674	1160	750	1085	0.65	0.94	128
421	1000	122.4	2	.49	.49	.393	2000	.000163	5880	.340	.001044	31 300	39 220	.80	6500	.000875	26 300	3.83	8.66	89 400	149 100	.60	.000543	970	605	1010	.62	1.04	120
422	980	120.7	2	.49	.49	.393	2000	.000174	5860	.360	.001197	35 900	40 010	.90	5500	.000959	28 800	3.83	8.66	97 900	148 700	.66	.000596	1040	665	1010	.64	.97	119
Average									5950	.365	.001169	35 100		.90								.65					.64	.98	122
432	1010	123.5	3	.74	.74	.589	3000	.000219	8810	.420	.001219	36 600	39 860	.92	8730	.001162	34 900	4.12	8.56	176 000	226 800	.78	.000815	1340	1125	1440	.84	1.07	121
433	1020	123.4	3	.74	.74	.589	2000	.000144	9400	.440	.001214	36 400	39 550	.92	9000	.001101	33 000	4.14	8.55	166 200	233 400	.71	.000778	1300	1055	1485	.81	1.14	125
434	990	119.5	3	.74	.74	.589	3000	.000211	9270	.435	.001200	36 000	40 520	.89	9000	.001065	32 000	4.42	8.45	159 300	232 900	.68	.000842	1380	960	1410	.70	1.02	126
Average									9160	.432	.001211	36 300		.91								.72					.78	1.08	124
444	1000	120.5	4	.98	.98	.785	2000	.000138	12 000	.515	.001285	38 600	39 900	.97	12 000	.001285	38 600	4.64	8.38	254 100	305 100	.83	.001111	1640	1470	1770	.90	1.08	124
445	1000	118.1	II	.98	.98	.785	3000	.000205	11 750	.525	.001381	41 400	39 780	1.04	11 000	.001164	34 900	4.44	8.45	231 600	281 100	.82	.000931	1480	1390	1695	.94	1.15	113
446	1000	120.9	4	.98	.98	.785	2000	.000146	12 000	.535	.001482	44 500	41 670	1.07	11 000	.001209	36 300	4.56	8.40	239 500	281 100	.85	.001014	1560	1405	1655	.90	1.06	114
Average									11 920	.525	.001383	41 500		1.03								.83					.91	1.10	117
456	990	119.5	5	1.23	1.11	.982	2000	.000144	12 500	.550	.001482	44 500	38 780	1.15	12 000	.001244	37 300	4.88	8.29	252 500	304 900	.83	.001184	1700	1490	1795	.88	1.06	120
457	1020	122.5	5	1.23	1.11	.982	3000	.000193	14 000	.615	.001571	47 100	38 000	1.24	13 000	.001320	39 600	4.72	8.35	271 100	329 400	.82	.001181	1700	1645	2005	.97	1.18	128
458	1010	121.6	5	1.23	1.11	.982	2000	.000149	13 200	.620	.001610	48 300	40 810	1.18	12 000	.001221	36 600	4.92	8.28	247 200	305 200	.81	.001183	1700	1450	1790	.85	1.05	121
Average									13 230	.595	.001554	46 600		1.19								.82					.90	1.10	123
468	1000	120.5	II	1.47	1.30	1.178	2000	.000122	14 560	.585	.001188	35 600	38 010	.94	14 000	.001128	33 800	5.39	8.11	250 300	353 100	.71	.001317	1800	1395	1965	.78	1.09	127
469	1000	118.3	6	1.47	1.30	1.178	2000	.000135	14 550	(.595)	.001296	38 900	37 970	1.02	14 000	.001209	36 300	5.29	8.15	271 200	353 100	.77	.001360	1820	1530	1985	.84	1.09	126
470	990	118.6	6	1.47	1.30	1.178	2000	.000144	15 000	(.599)	.001747	52 400	37 630	1.39	14 000	.001344	40 300	5.10	8.22	305 800	352 900	.87	.001399	1840	1775	2040	.96	1.11	124
Average									14 700	.593	.001410	42 300		1.12								.78					.86	1.10	126
480	1010	120.4	7	1.72	1.54	1.375	3000	.000194	16 550	.645	.001547	46 400	36 110	1.28	15 000	.001125	33 800	5.36	8.12	304 800	377 200	.81	.001297	1780	1680	2075	.94	1.17	111
481	1020	119.0	7	1.72	1.54	1.375	2000	.000122	17 150	1.985	[1] .003130	[1] 93 900	36 260	[1] 2.59	15 000	.001137	34 100	5.48	8.08	304 700	377 400	.81	.001377	1830	1650	2035	.90	1.11	112
482	980	115.7	7	1.72	1.54	1.375	2000	.000119	17 500	(.735)	.001785	53 600	36 980	1.45	16 000	.001183	35 500	5.61	8.04	314 100	400 700	.78	.001511	1910	1670	2140	.87	1.12	120
Average									17 100	.690	.001666	50 000		1.37								.80					.90	1.13	114
492	1010	117.9	III	1.96	1.72	1.571	3000	.000186	18 060	.760	.001726	51 800	37 210	1.39	16 000	.001164	34 900	5.61	8.04	338 300	401 200	.84	.001487	1900	1820	2165	.96	1.14	110
493	1030	118.4	8	1.96	1.72	1.571	4000	.000232	17 850	.785	.001600	48 000	38 190	1.26	17 000	.001224	36 700	5.66	8.02	354 100	425 600	.83	.001596	1950	1820	2285	.93	1.17	117
494	1020	121.3	8	1.96	1.72	1.571	3000	.000187	18 140	.805	.001807	54 200	36 440	1.49	16 000	.001149	34 500	5.66	8.02	332 900	401 400	.83	.001501	1900	1780	2145	.94	1.13	110
Average									18 020	.783	.001711	51 300		1.38								.83					.96	1.15	112
Grand Ave		120.1					2400	.000163																				1.09	120

[1] Not used in average.

Remarks.—Average bond stress developed in beam—120 pounds per square inch. Average ultimate bond stress from bond test pieces—547 pounds per square inch. Ratio—4.5.

Note.—Values in parentheses are estimated.

Table 20.—Cinder Concrete. Proportions, 1:2:4. Age, 26 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D−.35KD in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr / Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
423	1000	122.4	2	0.49	0.49	0.393	2000	0.000134	6610	0.360	0.001101	33 000	38 220	0.86	6500	0.000933	28 000	3.88	8.64	95 000	173 100	0.55	0.000591	1210	640	1165	0.53	0.96	139
424	990	121.0	2	.49	.49	.393	2500	.000156	6460	.325	.000945	28 400	38 770	.73	6000	.000848	25 400	3.82	8.66	86 400	160 900	.54	.000525	1090	585	1065	.54	1.00	129
425	990	121.0	2	.49	.49	.393	2500	.000191	6320	.330	.001029	30 900	39 680	.78	6000	.000904	27 100	3.71	8.70	92 600	160 900	.58	.000534	1110	645	1110	.58	1.00	128
Average									6460	.342	.001025	30 800		.79								.56					.55	.99	132
435	980	120.4	2	.74	.74	.589	2500	.000173	9500	.420	.001210	36 300	40 230	.90	9000	.001019	30 600	4.36	8.47	152 700	232 700	.66	.000786	1510	930	1410	.62	.93	125
436	1000	119.9	3	.74	.74	.589	3000	.000195	9300	.410	.001202	36 100	40 450	.89	9000	.001072	32 200	4.63	8.59	162 900	233 100	.70	.000724	1420	1060	1515	.75	1.07	124
437	[illegible]	119.3	3	.74	.74	.589	2500	.000159	9550	.435	.001253	37 600	40 480	.93	9000	.001056	31 700	4.11	8.56	159 800	232 700	.69	.000738	1440	1020	1480	.71	1.03	124
Average									9450	.422	.001222	36 700		.91								.68					.69	1.01	124
447	970	116.5	4	.98	.98	.785	3000	.000179	12 600	.500	.001354	40 600	41 350	.98	12 000	.001096	32 900	4.74	8.34	215 500	304 600	.71	.000986	1780	1225	1725	.69	.97	124
448	990	117.4	4	.98	.98	.785	3000	.000169	12 830	.515	.001311	39 300	40 850	.96	12 000	.001120	33 600	4.50	8.43	222 500	304 900	.73	.000916	1690	1320	1810	.78	1.07	123
449	990	118.5	4	.98	.98	.785	4000	.000241	13 000	.510	.001376	41 300	39 740	1.04	12 000	.001109	33 300	4.60	8.39	219 400	304 900	.72	.000944	1730	1280	1780	.74	1.03	123
Average									12 810	.508	.001347	40 400		.99								.72					.74	1.02	123
459	990	117.9	5	1.23	1.11	.982	3000	.000179	13 730	.525	.001315	39 500	38 950	1.01	13 000	.001195	35 900	4.74	8.34	245 300	328 900	.75	.001075	1880	1485	1980	.79	1.05	128
460	990	116.9	5	1.23	1.11	.982	3000	.000174	13 980	.530	.001385	41 600	39 050	1.07	13 000	.001234	37 000	4.49	8.43	257 000	328 900	.78	.001096	1800	1620	2075	.90	1.15	126
461	980	118.9	5	1.23	1.11	.982	3000	.000182	13 100	.570	.001272	38 200	36 880	1.04	13 000	.001221	36 600	4.78	8.33	249 600	328 700	.76	.001117	1930	1495	1965	.77	1.02	128
Average									13 600	.542	.001324	39 800		1.04								.76					.82	1.07	127
471	990	118.0	6	1.47	1.30	1.178	3000	.000172	15 400	.585	.001545	46 400	38 100	1.22	14 000	.001109	33 300	5.16	8.19	251 200	352 900	.71	.001182	2000	1445	2035	.72	1.02	124
472	990	117.1	6	1.47	1.30	1.178	3000	.000176	15 570	.640	.001561	46 800	36 800	1.27	14 000	.001156	34 700	4.92	8.28	267 000	352 900	.76	.001119	1930	1595	2100	.83	1.09	122
473	990	118.5	6	1.47	1.30	1.178	3000	.000174	15 000	.590	.001565	47 000	37 940	1.24	14 000	.001195	35 900	4.90	8.29	276 700	352 900	.78	.001146	1960	1655	2120	.84	1.08	122
Average									15 320	.605	.001557	46 700		1.24								.75					.80	1.06	123
483	1000	117.5	7	1.72	1.54	1.375	3000	.000172	17 000	.655	.001638	49 100	35 920	1.37	16 000	.001232	37 000	5.27	8.16	366 300	401 100	.84	.001371	2190	1875	2230	.86	1.02	117
484	1020	119.4	7	1.72	1.54	1.375	3000	.000166	17 550	(.640)	.001540	46 200	36 460	1.27	17 000	.001308	39 200	5.23	8.17	357 200	425 400	.85	.001433	[1] 2240	2005	2360	.90	1.05	124
485	1010	119.3	7	1.72	1.54	1.375	3000	.000167	17 000	.615	.001482	44 500	36 880	1.21	15 000	.001067	32 000	5.39	8.11	287 900	377 200	.76	.001249	2060	1580	2080	.77	1.01	111
Average									17 180	.637	.001553	46 600		1.28								.82					.84	1.03	117
495	1000	117.2	8	1.96	1.72	1.571	3000	.000154	19 730	.680	.001602	48 100	37 140	1.30	18 100	.001174	35 200	5.64	8.03	340 400	451 500	.75	.001521	[1] 2320	1825	2435	.79	1.05	124
496	1030	120.4	8	1.96	1.72	1.571	4000	.000212	19 700	.690	.001579	47 400	36 790	1.29	18 000	.001217	36 500	5.34	8.13	361 900	449 600	.81	.001392	2200	2025	2500	.92	1.14	120
497	1010	118.5	8	1.96	1.72	1.571	5000	.000249	20 000	.690	.001385	41 600	37 820	1.10	19 000	.001191	35 700	5.57	8.05	347 100	473 200	.73	.001499	[1] 2300	1880	2575	.82	1.12	129
Average									19 810	.687	.001522	45 700		1.23								.76					.84	1.10	124
Grand Ave		118.9					3000	.000180																				1.04	124

[1] Values taken from average curve produced.

Remarks.—Average bond stress developed in beam=124 pounds per square inch. Average ultimate bond stress from bond test pieces=397 pounds per square inch. Ratio=32.

Note.—Values in parentheses are estimated.

Table 21.—Cinder Concrete. Proportions, 1:2:4. Age, 52 Weeks

426	970	120.8	2	0.49	0.49	0.393	2500	0.000186	6460	(0.343)	0.001161	34 800	38 890	0.89	6000	0.000889	26 700	3.95	8.62	90 400	160 050	.565	0.000579	1220	595	1055	0.49	0.86	129
427	960	120.2	2	.49	.49	.393	2000	.000151	6500	.385	[1].000926	27 800	38 480	.72	6500	.000926	27 800	4.24	8.52	93 000	172 400	.539	.000680	1400	580	1075	.41	.77	140
428	980	122.5	2	.49	.49	.393	2000	.000145	6400	(.340)	[1].000949	28 500	37 660	.76	6000	.000809	24 300	4.20	8.53	81 400	160 950	.506	.000586	1238	570	1010	.41	.82	131
Average									6450	.356	.001161	30 370		.79								.537					.44	.82	136
438	930	115.2	3	.74	.74	.589	2000	.000143	9500	(.459)	.001325	39 800	40 290	.99	9000	.001125	33 800	4.45	8.44	168 100	231 950	.725	.000901	1760	1005	1385	.57	.79	125
439	960	119.2	3	.74	.74	.589	2500	.000171	9930	(.444)	.001174	35 200	40 850	.86	9000	.001009	30 300	4.47	8.44	150 700	232 400	.648	.000816	1630	1000	1290	.55	.85	125
440	960	118.3	3	.74	.74	.589	3000	.000202	9850	(.462)	(.001183)	35 500	41 040	.87	9000	.001034	31 000	4.40	8.46	154 500	232 400	.665	.000813	1620	935	1405	.58	.87	125
Average									9760	(.455)	.001227	36 830		.91								.679					.57	.84	125
450	960	118.3	4	.98	.98	.785	3000	.000181	12 000	.500	.001272	38 200	41 650	.92	12 000	.001272	38 200	4.69	8.37	251 100	304 450	.825	.001122	2060	1440	1745	.70	.85	123
451	960	115.0	4	.98	.98	.785	2000	.000126	12 000	(.482)	.001297	38 900	41 050	.95	11 000	.001120	33 600	4.69	8.37	220 900	280 450	.788	.000987	1880	1265	1605	.67	.85	114
452	950	116.6	4	.98	.98	.785	3000	.000190	12 000	.505	.001227	36 800	40 610	.91	12 000	.001227	36 800	4.68	8.37	241 900	304 400	.795	.001079	2010	1390	1750	.69	.87	123
Average									12 000	.496	.001265	37 970		.93								.803					.69	.86	120
462	960	115.6	5	1.23	1.11	.982	3000	.000243	13 900	(.558)	(.001314)	39 400	37 420	1.05	13 000	.001186	35 600	4.13	8.35	243 600	329 550	.739	.001065	1990	1475	1995	.74	1.00	128
463	970	117.4	5	1.23	1.11	.982	3000	.000209	13 350	(.534)	.001303	39 100	37 460	1.04	13 000	.001226	36 800	4.72	8.35	251 900	328 600	.767	.001095	2030	1525	1930	.75	.98	128
464	960	117.4	5	1.23	1.11	.982	2000	.000133	13 250	(.554)	.001379	41 400	38 800	1.07	13 000	.001238	37 100	4.90	8.29	251 100	328 450	.765	.001187	2130	1475	1930	.69	.91	139
Average									13 500	(.549)	.001332	39 970		1.05								.757					.73	.96	138
474	970	117.9	6	1.47	1.30	1.178	3000	.000257	14 480	(.628)	(.001480)	44 400	36 710	1.21	13 000	.001150	34 500	5.06	8.23	262 500	329 750	.796	.001179	2130	1535	1930	.72	.91	115
475	990	117.8	6	1.47	1.30	1.178	4000	.000230	15 250	(.580)	.001285	38 600	38 770	1.00	15 000	.001246	37 400	4.94	8.28	287 600	376 950	.763	.001217	2170	1710	2240	.79	1.03	130
476	970	118.8	6	1.47	1.30	1.178	3000	.000188	14 240	(.607)	.001668	50 000	37 400	1.34	13 000	.001215	36 500	5.02	8.25	278 900	328 600	.849	.001223	2180	1635	1925	.75	.88	114
Average									14 660	(.605)	.001478	44 330		1.18								.803					.75	.94	120
486	960	116.5	7	1.72	1.54	1.375	3000	.000255	17 000	.675	.001572	47 200	37 620	1.25	15 000	.001026	30 800	5.68	8.01	270 900	377 600	.717	.001347	2300	1430	1995	.62	.87	114
487	990	116.3	7	1.72	1.54	1.375	4000	.000214	18 000	.620	.001350	40 500	37 230	1.09	17 000	.001207	36 200	5.30	8.15	328 300	424 900	.773	.001360	2320	1825	2360	.79	1.02	124
488	990	117.8	7	1.72	1.54	1.375	3500	.000166	17 850	(.660)	.001603	48 100	37 230	1.29	16 000	.001174	35 200	5.25	8.17	320 500	400 900	.799	.001300	2260	1795	2245	.79	1.99	117
Average									17 620	.652	.001508	45 270		1.21								.763					.73	.96	118
498	1000	119.4	8	1.96	1.72	1.571	4100	.000214	19 250	(.696)	.001665	50 000	37 760	1.32	18 000	.001256	37 700	5.59	8.04	365 900	449 100	.815	.001590	2520	[illegible]	2430	.79	.96	122
499	1020	120.3	8	1.96	1.72	1.571	3100	.000225	19 800	(.700)	(.001708)	51 200	38 620	1.33	18 000	.001210	36 300	5.41	8.11	358 100	450 600	.795	.001426	2370	[illegible]	2495	.84	1.05	121
500	1000	118.9	8	1.96	1.72	1.571	4000	.000209	19 760	(.704)	.001658	49 700	37 760	1.32	18 000	.001198	35 900	5.44	8.10	353 200	449 100	.786	.001428	2380	[illegible]	2480	.82	1.04	121
Average									19 600	(.700)	.001677	50 300		1.32								.799					.82	1.02	121
Grand Ave		118.1					2900	.000192																				.91	124

[1] Not used in average.

Remarks.—Average bond stress developed in beam=124 pounds per square inch. Average ultimate bond stress from bond test pieces=462 pounds per square inch. Ratio=3.7.

Note.—Values in parentheses estimated.

Table 18.—Cinder Concrete. Proportions 1:2:4. Age, 4 Weeks

Beam Number	Total Weight of Beam, in lbs.	Weight per cu. ft., in lbs.	Reinforcement: Number of ½" round rods	Reinforcement: Nominal Per cent	Reinforcement: Effective Per cent	Reinforcement: Area, in sq. in.	First Crack: Applied Load, in lbs.	First Crack: Unit Elongation in Lower Fiber, inches per inch	Maximum Load: Applied Load, in lbs.	Maximum Load: Deflection, inches	Maximum Load: Unit Elongation in Steel, inches per inch	Maximum Load: Unit Stress of Steel, lbs. per sq. in. S_1	Maximum Load: Yield Point of Steel, lbs. per sq. in. S_2	$S_1 \div S_2$	Analysis of beam at Unit Elongation in Reinforcement Less than that at Yield Point: Applied Load, in lbs.	Unit Elongation in Steel, inches per inch	Unit Stress in Steel, lbs. per sq. in.	KD, in inches	D–35 KD, in inches	Resisting Moment, inch lbs., Mr	Bending Moment, inch lbs., Mb	Mr ÷ Mb	Unit Deformation Upper Fiber, inches per inch	Unit Compressive Stress Upper Fiber, lbs. per sq. in.: C_1 from Cylinder Curve	C_2 from Resisting Moment	C_3 from Bending Moment	$C_2 \div C_1$	$C_3 \div C_1$	Unit Bond Stress, lbs. per sq. in.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
417	970	120.8	2	0.49	0.49	0.393	2000	0.000195	5900	0.440	0.001169	35 100	36 960	0.95	5500	0.001009	30 300	4.06	8.58	102 100	148 600	0.69	0.000688	940	650	925	0.70	1.02	120
418	980	121.4	2	.49	.49	.393	1500	.000133	5900	.385	.001132	34 000	37 720	.90	5500	.000976	29 300	4.08	8.57	98 600	148 700	.66	.000674	930	635	960	.68	1.03	121
419	950	117.6	2	.49	.49	.393	2000	.000201	6390	.445	.001294	38 800	37 390	1.04	6000	.001205	36 200	4.11	8.56	121 700	160 300	.76	.000840	1080	780	1025	.72	.95	130
Average									6060	.423	.001198	36 000		.96								.70				.70	1.00	124
429	990	121.8	[illegible]	.74	.74	.589	2000	.000157	8700	.520	.001405	42 200	39 090	1.08	8500	.001311	39 300	4.50	8.43	195 200	220 900	.88	.001073	1240	1160	1320	.94	1.06	120
430	990	122.5	3	.74	.74	.589	2000	.000171	8760	.520	.001362	40 900	40 490	1.01	8500	.001236	37 100	4.65	8.37	182 900	220 900	.83	.001072	1240	1060	1275	.85	1.03	121
431	980	121.9	[illegible]	.74	.74	.589	2500	.000199	8940	.505	.001234	37 000	41 300	.90	8500	.001113	33 400	4.81	8.32	163 700	220 700	.74	.001032	1210	920	1245	.76	1.03	121
Average									8800	.515	.001334	40 000		1.00								.82				.85	1.04	121
441	960	119.2	4	.98	.98	.785	2000	.000166	10 500	.585	.001414	42 400	40 520	1.05	10 000	.001215	36 500	5.50	8.08	231 600	256 400	.90	.001487	1410	1175	1305	.83	.93	108
442	970	119.1	4	.98	.98	.785	2000	.000153	10 900	.595	(.001335)	(40 100)	41 840	.96	10 500	.001186	35 600	5.54	8.06	225 300	268 600	.84	.001471	1400	1135	1350	.81	.96	113
443	970	118.3	4	.98	.98	.785	3000	.000249	11 470	.625	(.001458)	(43 700)	41 150	1.06	10 000	.001060	31 800	5.43	8.10	202 300	256 600	.79	.001258	1330	1035	1310	.78	.99	[illegible]
Average									10 960	.602	.001402	(42 100)		1.02								.84				.81	.96	110
453	960	118.6	5	1.23	1.11	.982	2000	.000173	11 700	.740	.001684	50 500	40 330	1.25	11 000	.001246	37 400	5.70	8.01	238 700	280 400	.85	.001654	[1] 1460	1245	1465	.85	1.00	117
454	980	118.8	5	1.23	1.11	.982	2000	.000176	11 130	.765	.001655	49 700	38 210	1.30	10 000	.001126	33 800	5.59	8.04	217 400	256 700	.85	.001431	1390	1155	1360	.83	.98	107
455	980	119.5	[illegible]	1.23	1.11	.982	2000	.000170	11 450	.665	.001508	45 200	39 750	1.14	10 000	.001097	32 900	5.36	8.12	215 300	256 700	.84	.001268	1340	1180	1405	.88	1.05	105
Average									11 430	.723	.001616	48 500		1.23								.85				.85	1.01	110
465	970	118.1	6	1.47	1.30	1.178	2000	.000164	13 100	(.760)	(.001660)	(49 800)	36 980	1.35	12 000	.001231	36 900	5.93	7.92	260 200	304 600	.85	.001790	[1] 1500	1345	1580	.90	1.05	115
466	980	117.4	6	1.47	1.30	1.178	2000	.000157	13 460	.810	(.001906)	(57 200)	37 870	1.51	12 000	.001176	35 300	5.71	8.00	254 200	304 700	.83	.001566	[1] 1440	1350	1625	.94	1.13	113
467	930	119.6	6	1.47	1.30	1.178	2000	.000153	14 100	.845	(.001762)	(52 900)	37 350	1.42	13 500	.001318	39 500	5.67	8.02	285 800	340 700	.84	.001726	[1] 1480	1530	1820	1.03	1.23	125
Average									13 550	.805	.001776	(53 300)		1.43								.84				.96	1.14	118
477	990	119.2	7	1.72	1.54	1.375	3000	.000219	14 870	.885	.001925	57 800	36 730	1.57	13 000	.001179	35 400	5.86	7.95	306 900	328 900	.93	.001668	[1] 1460	1580	1700	1.08	1.16	101
478	980	116.4	7	1.72	1.54	1.375	3000	.000213	14 590	.870	.001701	51 000	35 790	1.42	13 000	.001198	35 900	5.82	7.96	312 000	328 700	.95	.001669	[1] 1460	1615	1700	1.11	1.16	101
479	980	117.1	7	1.72	1.54	1.375	2000	.000146	15 170	.875	(.001949)	(58 500)	37 620	1.56	13 000	.001097	32 900	5.93	7.92	283 100	328 700	.86	.001598	[1] 1440	1445	1680	1.00	1.17	102
Average									14 880	.877	.001858	(55 800)		1.52								.91				1.06	1.16	101
489	990	118.9	8	1.96	1.72	1.571	2000	.000148	15 750	.980	(.002046)	(61 400)	38 020	1.61	13 000	.001094	32 800	6.28	7.80	297 800	328 900	.91	.001844	[1] 1510	1475	1620	.98	1.07	96
490	1000	117.5	8	1.96	1.72	1.571	3000	.000219	16 000	1.005	.001974	59 200	37 690	1.57	13 000	.001055	31 700	6.09	7.87	293 700	329 100	.89	.001641	[1] 1460	1485	1670	1.02	1.14	95
491	1000	150.0	8	1.96	1.72	1.571	3000	.000208	16 410	1.000	(.001993)	(59 800)	37 950	1.58	14 000	.001145	34 400	6.06	7.88	319 600	353 100	.90	.001765	[1] 1490	1625	1805	1.09	1.21	101
Average									16 050	.995	.002004	(60 100)		1.59								.90				1.03	1.14	97
Grand Ave		119.0					2200	.000180																			1.08	111

Note.—Values in parentheses are estimated.

[1] Values taken from average curve produced.

Table 19.—Cinder Concrete. Proportions 1:2:4. Age, 13 Weeks

420	960	119.2	2	0.49	0.49	0.393	1000	0.000094	6120	0.395	0.001265	38 000	38 400	0.99	6000	0.001085	32 600	3.83	8.66	110 900	160 400	0.69	0.000674	1160	750	1085	0.65	0.94	128
421	1000	122.4	[illegible]	.49	.49	.393	2000	.000163	5880	.340	.001044	31 300	39 220	.80	6500	.000875	26 300	3.83	8.66	89 400	149 100	.60	.000543	970	605	1010	.62	1.04	120
422	980	120.7	2	.49	.49	.393	2000	.000174	5860	.360	.001197	35 900	40 010	.90	5500	.000959	28 800	3.83	8.66	97 900	148 700	.66	.000596	1040	665	1010	.64	.97	119
Average									5950	.365	.001169	35 100		.90								.65				.64	.98	122
432	1010	123.5	3	.74	.74	.589	3000	.000219	8810	.420	.001219	36 600	39 860	.92	8730	.001162	34 900	4.12	8.56	176 000	226 800	.78	.000815	1340	1125	1440	.84	1.07	121
433	1020	123.4	3	.74	.74	.589	2000	.000144	9400	.440	.001214	36 400	39 550	.92	9000	.001101	33 000	4.14	8.55	166 200	233 400	.71	.000778	1300	1055	1485	.81	1.14	125
434	990	119.5	3	.74	.74	.589	3000	.000211	9270	.435	.001200	36 000	40 520	.89	9000	.001065	32 000	4.42	8.45	159 300	232 900	.68	.000842	1380	980	1410	.70	1.02	126
Average									9160	.432	.001211	36 300		.91								.72				.78	1.08	124
444	1000	120.5	4	.98	.98	.785	2000	.000138	12 000	.515	.001285	38 600	39 900	.97	12 000	.001285	38 600	4.64	8.38	254 100	305 100	.83	.001111	1640	1470	1770	.90	1.08	124
445	1000	118.1	4	.98	.98	.785	3000	.000205	11 750	.525	.001381	41 400	39 780	1.04	11 000	.001164	34 900	4.44	8.45	231 600	281 100	.82	.000931	1480	1390	1695	.94	1.15	113
446	1000	120.9	4	.98	.98	.785	2000	.000146	12 000	.535	.001482	44 500	41 670	1.07	11 000	.001209	36 300	4.56	8.40	239 500	281 100	.85	.001014	1560	1405	1655	.90	1.06	114
Average									11 920	.525	.001383	41 500		1.03								.83				.91	1.10	117
456	990	119.5	5	1.23	1.11	.982	2000	.000144	12 500	.550	.001482	44 500	38 780	1.15	12 000	.001244	37 300	4.88	8.29	252 500	304 900	.83	.001184	1700	1490	1795	[illegible]	1.06	120
457	1070	122.5	5	1.23	1.11	.982	3000	.000193	14 000	.615	.001571	47 100	38 000	1.24	13 000	.001320	39 600	4.72	8.35	271 100	329 400	.82	.001181	1700	1645	2005	.97	1.18	128
458	1010	121.6	5	1.23	1.11	.982	2000	.000149	13 200	.620	.001610	48 300	40 810	1.18	12 000	.001221	36 600	4.92	8.28	247 200	305 200	.81	.001183	1700	1450	1790	.85	1.05	121
Average									13 230	.595	.001554	46 600		1.19								.82				.90	1.10	123
468	1000	120.5	6	1.47	1.30	1.178	2000	.000122	14 560	.585	.001188	35 600	38 010	.94	14 000	.001128	33 800	5.39	8.11	250 300	353 100	.71	.001317	1800	1395	1965	.78	1.09	127
469	1000	118.3	6	1.47	1.30	1.178	2000	.000135	14 550	(.595)	.001296	38 900	37 970	1.02	14 000	.001209	36 300	5.29	8.15	271 200	353 100	.77	.001360	1820	1530	1985	.84	1.09	126
470	990	118.6	6	1.47	1.30	1.178	2000	.000144	15 000	(.599)	.001747	52 400	37 630	1.39	14 000	.001344	40 300	5.10	8.22	305 800	352 900	.87	.001399	1840	1775	2040	.96	1.11	124
Average									14 700	.593	.001410	42 300		1.12								.78				.86	1.10	126
480	1010	120.4	7	1.72	1.54	1.375	3000	.000194	16 650	.645	.001547	46 400	36 110	1.28	15 000	.001125	33 800	5.36	8.12	304 800	377 200	.81	.001297	1780	1680	2075	.94	1.17	111
481	1020	119.0	7	1.72	1.54	1.375	2000	.000122	17 150	1.985	[1] .003130	[1] 93 900	36 260	[1] 2.59	15 000	.001137	34 100	5.48	8.08	304 700	377 400	.81	.001377	1830	1650	2035	.90	1.11	112
482	980	115.7	7	1.72	1.54	1.375	2000	.000119	17 500	(.735)	.001785	53 600	36 980	1.45	16 000	.001183	35 500	5.61	8.04	314 100	400 700	.78	.001511	1910	1670	2140	.87	1.12	120
Average									17 100	.690	.001666	50 000		1.37								.80				.90	1.13	114
492	1010	117.9	[illegible]	1.96	1.72	1.571	3000	.000186	18 060	.760	.001726	51 800	37 210	1.39	16 000	.001164	34 900	5.61	8.04	338 300	401 200	.84	.001487	1900	1820	2165	.96	1.14	110
493	1030	118.4	[illegible]	1.96	1.72	1.571	4000	.000232	17 850	.785	.001600	48 000	38 190	1.26	17 000	.001224	35 700	5.66	8.02	354 100	425 600	.83	.001596	1950	1895	2285	.97	1.17	117
494	1020	121.3	8	1.96	1.72	1.571	3000	.000187	18 140	.805	.001807	54 200	36 440	1.49	16 000	.001149	34 500	5.66	8.02	332 900	401 400	.83	.001501	1900	1780	2145	.94	1.13	110
Average									18 020	.783	.001711	51 300		1.38								.83				.96	1.15	112
Grand Ave		120.1					2400	.000163																			1.09	120

[1] Not used in average.

Remarks.—Average bond stress developed in beam = 120 pounds per square inch. Average ultimate bond stress from bond test pieces = 547 pounds per square inch. Ratio = 4.5.

Note.—Values in parentheses are estimated.

Table 33.—Compression Tests on Granite Concrete of Medium Consistency Similar to that Used in Beams

[Proportions 1 : 2 : 4 by volume, or 1 : 2.01 : 3.81 by weight]

AGE, 4 WEEKS

Register number	Percentage of water	Cylinders: Dimensions: Diameter, inches	Cylinders: Dimensions: Length, inches	Cylinders: Weight, lbs. per cu. ft.	Cylinders: Ultimate strength, lbs. per sq. in.	Cylinders: Initial modulus of elasticity	Cylinders: Yield point	Cubes: Dimensions: Base, inches	Cubes: Dimensions: Height, inches	Cubes: Weight, lbs. per cu. ft.	Cubes: Ultimate strength, lbs. per sq. in.	Stress ratio of cylinders to cubes
162	8.3	8.02	16.16	148.7	3083	4 200 000	900	6.04 x 5.99	6.02	148.8	3803	.....
163	8.3	8.04	16.03	148.2	3521	4 100 000	900	6.03 x 6.03	6.07	144.9	4268	.....
164	8.3	8.03	16.08	149.3	3120	3 900 000	1000	6.02 x 6.04	5.98	150.0	3880	.....
174	8.3	7.98	16.02	148.8	3117	4 320 000	1000	6.01 x 6.01	6.09	147.3	4138	.....
175	8.3	8.02	16.04	149.3	3045	4 080 000	.....	6.03 x 6.02	6.03	146.0	3914	.....
176	8.3	8.03	15.99	146.7	2772	4 240 000	1000	6.02 x 6.01	5.98	149.8	4076	.....
186	8.3	7.99	15.75	149.3	3081	3 940 000	1000	6.03 x 6.03	5.98	145.1	3914	.....
187	8.3	8.02	15.00	148.6	2784	4 000 000	1000	5.99 x 5.98	6.00	148.7	3349	.....
188	8.3	8.00	16.25	147.5	2556	3 860 000	800	6.02 x 5.99	6.04	147.8	4060	.....
198	8.3	7.98	15.75	151.4	3234	4 200 000	1000	6.04 x 5.94	6.09	148.3	2190	.....
199	8.3	7.99	15.75	151.5	3311	3 920 000	1000	6.01 x 6.04	6.07	145.1	3657	.....
200	8.3	7.94	16.00	151.3	2989	3 980 000	1000	6.01 x 6.01	5.98	150.0	4101	.....
210	8.1	7.98	16.13	150.0	2879	4 200 000	800	6.00 x 6.00	6.14	148.5	3898	.....
211	8.0	8.01	15.75	151.3	2480	3 930 000	1000	6.02 x 6.02	6.09	147.8	4063	.....
212	8.0	8.02	16.00	148.0	2940	4 060 000	700	6.03 x 6.02	6.12	147.7	3581	.....
222	8.1	8.02	15.88	152.2	3393	4 980 000	1000	6.02 x 6.02	6.14	145.6	3907	.....
223	8.1	7.99	16.25	147.9	3312	4 380 000	1000	6.00 x 6.01	6.12	144.9	3674	.....
224	8.1	8.00	16.13	149.2	3036	5 660 000	800	6.03 x 5.98	6.16	147.9	3981	.....
237	8.1	7.99	15.75	152.6	3336	5 320 000	1000	6.03 x 6.03	6.07	146.8	4018	.....
238	8.1	8.02	15.75	150.4	3041	4 520 000	800	5.99 x 6.00	6.04	143.3	3930	.....
239	8.1	7.98	16.13	147.3	3097	4 230 000	.....	5.98 x 6.09	6.03	145.6	3439	.....
Average.		.....	.....	149.4	3054	4 290 000	950	.....	.....	.....	3802	0.803

AGE, 13 WEEKS

165	8.3	8.02	16.15	147.4	[1] 3959	4 640 000	900	6.03 x 6.03	6.09	146.4	5274	.....
166	8.3	8.00	16.04	149.5	[1] 3979	4 760 000	1100	6.08 x 5.95	6.08	147.4	5130	.....
167	8.3	8.06	16.07	147.0	[1] 3920	4 280 000	1000	6.04 x 6.03	6.12	145.4	5200	.....
177	8.3	8.01	16.03	148.1	[1] 3969	4 540 000	1100	6.04 x 6.03	6.03	146.3	5349	.....
178	8.3	8.00	16.00	148.0	[1] 3979	4 480 000	1300	6.04 x 6.03	6.06	146.8	5036	.....
179	8.3	8.02	16.02	147.1	[1] 3957	4 540 000	1300	6.10 x 6.02	6.03	146.4	5178	.....
189	8.3	8.01	16.01	149.1	[1] 3969	4 580 000	1000	6.00 x 6.05	6.08	146.8	4599	.....
190	8.3	8.05	16.07	147.9	[1] 3930	3 930 000	1800	6.01 x 6.00	6.03	148.1	5026	.....
191	8.3	8.00	16.08	148.0	[1] 3979	4 440 000	1000	6.04 x 6.02	6.07	144.9	4753	.....
201	8.3	7.99	16.03	147.8	[1] 3989	4 540 000	800	6.03 x 6.00	6.11	146.6	5017	.....
202	8.3	8.00	16.00	148.5	[1] 3680	4 460 000	1200	6.05 x 6.09	6.12	143.8	4525	.....
203	8.3	8.00	16.07	148.4	[1] 3979	4 440 000	2000	6.03 x 6.18	6.13	143.7	5137	.....
213	8.1	8.02	16.07	146.9	[1] 3959	4 600 000	1000	6.02 x 6.02	1.15	145.8	5251	.....
214	8.1	8.02	16.25	148.2	[1] 3959	4 080 000	1900	6.00 x 6.19	6.06	145.9	5201	.....
215	8.1	8.04	16.15	147.0	[1] 3939	4 780 000	1900	6.02 x 6.00	6.15	147.4	5188	.....
225	8.1	8.00	16.19	147.6	[1] 3978	4 050 000	2700	6.04 x 6.04	6.00	148.0	5017	.....
226	8.1	8.03	16.02	149.1	[1] 3949	4 270 000	1100	6.02 x 6.00	6.07	147.9	5180	.....
227	8.1	8.00	16.24	147.1	[1] 3978	4 250 000	1800	6.08 x 6.03	6.02	146.8	4973	.....
243	8.1	8.03	16.07	146.5	[1] 3949	4 540 000	1000	6.02 x 6.06	6.01	147.8	4936	.....
244	8.1	8.02	16.06	145.9	[1] 3959	4 480 000	1300	6.04 x 6.09	5.98	147.4	4948	.....
245	8.1	8.00	16.03	147.4	[1] 3978	4 360 000	1200	6.00 x 6.02	6.10	145.1	4919	.....
Average.		.....	.....	.....	.....	4 430 000	1350	.....	.....	.....	5040	[1] 0.823

[1] Exceeded capacity of testing machine of 200 000 lbs., equivalent to given stress.

Table 33.—Compression Tests on Granite Concrete of Medium Consistency Similar to that Used in Beams—Continued

AGE, 26 WEEKS

Register number	Percentage of water	Cylinders: Dimensions: Diameter, inches	Cylinders: Dimensions: Length, inches	Cylinders: Weight, lbs. per cu. ft.	Cylinders: Ultimate strength, lbs. per sq. in.	Cylinders: Initial modulus of elasticity	Cylinders: Yield point	Cubes: Dimensions: Base, inches	Cubes: Dimensions: Height, inches	Cubes: Weight, lbs. per cu. ft.	Cubes: Ultimate strength, lbs. per sq. in.	Stress of cylinders to Cubes
168	8.3	8.01	16.05	149.0	[1] 3969	4 210 000	2400	6.00 x 6.02	6.08	146.5	5537	.....
169	8.3	8.01	16.15	147.3	[1] 3969	4 360 000	1700	6.02 x 6.02	5.98	151.5	5519	.....
170	8.3	8.00	16.00	148.3	[1] 3979	4 520 000	1700	6.02 x 6.02	5.96	149.0	5519	.....
180	8.3	8.00	16.01	149.3	[1] 3979	4 000 000	1900	6.02 x 6.02	6.01	148.8	[1] 5519	.....
181	8.3	8.05	16.02	148.4	[1] 3930	4 640 000	1300	5.98 x 6.04	6.08	146.5	[1] 5538	.....
182	8.3	8.03	16.00	148.8	[1] 3949	3 940 000	2400	6.01 x 6.05	6.10	144.1	5501	.....
192	8.3	8.00	16.03	140.5	[1] 3979	4 120 000	1200	6.00 x 6.00	6.00	147.0	4017	.....
193	8.3	8.02	15.95	146.6	[1] 3959	4 260 000	1000	6.00 x 6.00	6.00	148.0	4890	.....
194	8.3	8.05	16.00	145.3	[1] 3930	3 990 000	1800	6.00 x 6.00	6.00	148.0	5094	.....
204	8.3	7.99	16.03	149.4	[1] 4007	4 720 000	1200	6.08 x 6.00	6.00	148.0	5483	.....
205	8.1	8.00	16.00	148.7	[1] 3979	5 000 000	2000	6.03 x 5.99	6.00	148.0	5100	.....
206	8.1	8.03	15.97	149.8	[1] 3949	4 540 000	1700	5.97 x 6.12	6.00	149.4	5255	.....
216	8.1	7.99	16.02	149.3	[1] 3989	4 800 000	1800	6.13 x 5.98	6.00	147.8	4747	.....
217	8.1	7.99	15.96	149.1	[1] 3989	4 300 000	2800	6.09 x 5.98	6.00	148.3	5055	.....
218	8.1	8.00	16.07	149.2	[1] 3979	4 320 000	1700	6.04 x 6.03	6.00	148.3	5519	.....
231	8.1	8.01	16.06	149.2	[1] 3969	4 600 000	2000	5.98 x 6.03	6.06	.....	5497	.....
232	8.1	8.03	16.00	148.7	[1] 3949	5 000 000	1100	6.00 x 6.00	6.02	146.5	5538	.....
233	8.1	8.02	16.02	149.1	[1] 3959	4 300 000	2200	6.03 x 5.98	6.08	150.3	[1] 5546	.....
240	8.1	8.00	16.02	149.7	[1] 3979	4 900 000	1300	6.01 x 6.00	6.07	147.5	5091	.....
241	8.1	8.01	16.00	147.5	[1] 3969	4 920 000	1200	6.01 x 5.99	6.15	146.8	5507	.....
242	8.1	8.00	16.02	148.3	[1] 3979	4 540 000	1600	6.03 x 6.04	6.06	146.4	5439	.....
Average.		.....	.....	.....	.....	4 480 000	1700	.....	.....	.....	(5239)	[1] 0.849

AGE, 52 WEEKS

171	8.3	8.04	16.01	148.8	5539	4 400 000	2300	6.01 x 6.09	6.02	147.5	6154	.....
172	8.3	8.02	16.03	148.4	5838	4 760 000	1900	6.00 x 6.09	6.02	147.8	5176	.....
173	8.3	7.99	15.98	149.1	5390	4 720 000	1900	6.00 x 6.00	6.00	149.0	5807	.....
183	8.3	7.98	15.92	149.5	4716	4 740 000	1500	6.01 x 6.02	6.01	148.6	5362	.....
184	8.3	8.00	16.04	148.9	5418	4 820 000	1200	6.03 x 6.00	6.00	149.3	6144	.....
185	8.3	8.00	16.05	147.2	5271	5 080 000	2000	6.03 x 6.00	6.01	148.1	6142	.....
195	8.3	8.02	16.00	149.9	5071	4 560 000	1700	6.02 x 5.99	6.00	147.8	4988	.....
196	8.3	8.00	16.02	148.3	5197	4 320 000	1800	6.01 x 6.02	6.01	149.5	5076	.....
197	8.3	7.98	16.00	148.9	4999	4 640 000	1600	6.04 x 6.02	6.01	147.3	5158	.....
207	8.1	8.02	16.00	150.3	5305	4 880 000	1900	5.98 x 6.15	6.03	146.1	6580	.....
208	8.1	8.00	15.98	149.5	5950	4 880 000	2300	6.02 x 6.08	6.01	148.3	6748	.....
209	8.1	7.98	16.02	150.4	5299	4 880 000	1900	6.01 x 6.06	6.03	150.5	6168	.....
219	8.1	8.00	16.12	148.7	5424	4 640 000	2100	6.00 x 6.07	6.01	149.0	6278	.....
220	8.1	8.01	16.12	149.2	4961	5 160 000	1500	5.98 x 6.07	6.00	148.8	6572	.....
221	8.1	7.98	16.08	149.8	5299	5 000 000	1800	6.01 x 6.09	6.01	148.3	6391	.....
228	8.1	8.00	16.07	147.6	5968	5 200 000	1700	6.02 x 6.12	5.99	147.3	6432	.....
229	8.1	8.01	16.13	148.8	5573	4 900 000	3100	6.04 x 6.17	6.01	146.6	5612	.....
230	8.1	8.02	16.12	148.1	5065	4 700 000	2700	5.94 x 6.16	6.06	148.1	5426	.....
234	8.1	7.99	16.05	148.8	4939	4 520 000	2300	5.99 x 6.09	6.01	147.8	6409	.....
235	8.1	8.01	15.96	148.2	5058	4 640 000	2300	6.01 x 6.13	6.02	147.2	5774	.....
236	8.1	8.00	15.98	147.7	4874	4 720 000	1700	6.02 x 6.09	6.03	146.6	6058	.....
Average.		.....	.....	.....	5086	4 770 000	1962	.....	.....	.....	5964	.852

[1] Exceeded capacity of testing machine of 200 000 lbs., equivalent to given stress.

Table 34.—Compression Tests on Limestone Concrete of Medium Consistency Similar to that Used in Beams

[Proportions 1:2:4 by volume, 1:2.01:3.91 by weight]

AGE, 4 WEEKS

Register number	Percentage of water	Cylinders						Cubes				Stress ratio of cylinders to cubes
		Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	Initial modulus of elasticity	Yield point	Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	
		Diameter, inches	Length, inches					Base, inches	Height, inches			
255	10.0	8.00	16.21	145.5	2350	3 480 000	600	6.00 x 6.01	6.21	143.7	2895	.....
256	10.0	8.01	16.20	145.2	2121	3 360 000	600	6.03 x 6.21	6.00	143.3	2935	.....
257	10.0	8.00	16.20	146.1	1890	4 400 000	700	6.00 x 6.00	6.30	142.9	3518	.....
261	10.0	7.99	16.01	146.4	2447	3 660 000	700	6.01 x 6.01	6.08	.....	3216	.....
262	10.0	8.01	16.00	146.5	2273	3 290 000	700	6.07 x 6.01	6.08	.....	3015	.....
263	10.0	8.02	16.00	145.4	1979	2 600 000	500	6.06 x 6.00	6.11	.....	3086	.....
273	10.0	8.01	16.12	146.5	2745	3 760 000	800	6.01 x 6.00	6.02	148.3	4116	.....
274	10.0	8.01	16.00	145.7	2542	3 790 000	700	6.08 x 6.08	6.07	144.5	3420	.....
275	10.0	7.99	16.13	146.1	2513	4 170 000	600	6.03 x 6.04	6.06	145.9	3664	.....
285	10.0	8.05	16.15	146.1	3078	3 640 000	900	6.04 x 6.01	6.12	154.6	3554	.....
286	10.0	8.08	16.10	146.0	2586	4 820 000	1300	6.06 x 6.04	6.01	145.3	4003	.....
287	10.0	8.02	16.09	145.6	2679	3 800 000	1000	6.03 x 6.04	6.14	144.9	3655	.....
297	10.0	8.03	16.06	145.2	2344	2 990 000	900	6.03 x 6.02	6.05	146.6	3446	.....
298	10.0	8.01	16.11	145.3	2997	3 340 000	700	6.03 x 6.06	6.03	146.1	3293	.....
299	10.0	8.02	16.12	144.9	2178	3 750 000	700	6.01 x 6.02	6.03	145.5	3015	.....
318	10.0	8.01	16.01	147.2	2653	3 510 000	900	6.00 x 6.05	6.16	143.0	3581	.....
319	10.0	8.04	16.14	145.8	2535	3 525 000	900	6.01 x 6.04	6.11	144.1	3325	.....
320	10.0	8.08	16.04	143.9	1853	2 940 000	700	6.03 x 6.02	6.17	142.7	3085	.....
321	10.0	7.98	16.11	146.6	2859	3 660 000	900	6.05 x 6.02	6.04	143.4	3405	.....
322	10.0	8.01	16.11	147.1	2897	3 590 000	1000	6.05 x 6.25	6.00	139.0	3485	.....
323	10.0	8.03	16.03	145.3	2419	3 230 000	800	6.01 x 6.05	5.99	143.9	3511	.....
Average.		.....	.....	.....	2492	3 590 000	800	.....	.....	.....	3392	0.735

AGE, 13 WEEKS

249	10.0	8.01	16.04	146.4	3417	3 440 000	1700	6.01 x 6.00	6.13	144.6	4332	.....
250	10.0	8.03	16.07	146.0	3483	4 160 000	800	6.02 x 6.03	6.12	145.9	4118	.....
251	10.0	8.00	16.20	146.4	3481	3 900 000	1300	6.04 x 5.98	6.16	145.7	4489	.....
264	10.0	8.02	16.10	144.5	3609	3 790 000	1100	6.02 x 6.04	6.03	143.9	4410	.....
265	10.0	8.02	16.00	147.0	3569	3 930 000	2000	6.02 x 6.04	6.04	145.6	4368	.....
266	10.0	8.02	16.25	144.2	3768	4 150 000	900	6.02 x 6.05	6.10	144.0	4377	.....
276	10.0	8.01	16.02	146.6	3878	4 110 000	1500	6.02 x 6.09	6.03	142.7	5111	.....
277	10.0	8.01	16.04	147.5	[1] 3969	4 460 000	1100	6.01 x 6.11	6.02	144.6	4303	.....
278	10.0	8.02	16.01	145.3	3959	3 900 000	1500	5.90 x 6.02	6.08	145.9	4541	.....
288	10.0	8.00	16.08	147.0	3777	3 980 000	1200	6.01 x 6.05	6.15	142.9	5123	.....
289	10.0	.....	.....	.....	.....	.....	.....	6.03 x 6.02	6.12	142.0	4905	.....
290	10.0	8.01	16.11	146.3	[1] 3969	4 260 000	900	6.05 x 6.00	6.14	143.5	4602	.....
300	10.4	8.01	16.20	145.5	3494	2 400 000	2700	6.03 x 6.07	6.00	137.7	4025	.....
301	10.0	8.03	16.03	144.7	3306	3 660 000	1400	6.04 x 6.17	6.03	134.6	3713	.....
302	10.0	8.04	16.14	143.9	2826	3 990 000	1500	5.98 x 6.02	6.12	135.4	3815	.....
312	10.2	7.99	16.09	146.7	3968	3 400 000	2000	6.03 x 6.13	6.03	135.7	4645	.....
313	10.0	8.00	16.20	145.4	3562	3 885 000	1500	6.02 x 6.03	6.04	140.0	4083	.....
314	10.0	8.00	16.08	145.4	3362	2 980 000	1500	6.01 x 6.03	6.01	140.8	4331	.....
324	10.0	7.98	16.06	147.6	3826	4 180 000	1700	6.03 x 6.03	6.05	147.4	4300	.....
325	10.0	7.99	16.08	147.1	3809	3 860 000	1200	6.02 x 6.02	6.06	145.6	4548	.....
326	10.0	8.00	16.05	146.7	3700	3 790 000	1400	6.06 x 6.15	6.02	142.5	4387	.....
Average.		.....	.....	.....	3600	3 810 000	1450	.....	.....	.....	4421	0.814

[1] Exceeded capacity of testing machine of 200 000 lbs., equivalent to given stress.

Table 34.—Compression Tests on Limestone Concrete of Medium Consistency Similar to that Used in Beams—Continued

AGE, 26 WEEKS

Register number	Percentage of water	Cylinders						Cubes				Stress of cylinders to Cubes
		Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	Initial modulus of elasticity	Yield point	Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	
		Diameter, inches	Length, inches					Base, inches	Height, inches			
252	10.0	7.99	16.09	147.4	3636	4 400 000	1500	6.04 x 6.00	6.11	146.4	4238	.....
253	10.0	8.00	16.09	147.6	3327	4 280 000	1600	6.06 x 6.01	6.11	144.6	4106	.....
254	10.0	7.99	16.03	147.0	3577	4 120 000	1300	5.99 x 6.01	6.08	147.0	4115	.....
267	10.0	7.99	16.10	148.1	3901	3 940 000	1400	5.98 x 6.02	6.12	145.6	4838	.....
268	10.0	7.99	16.04	147.3	3761	4 040 000	1800	6.04 x 6.02	6.04	147.5	4903	.....
269	9.8	8.00	16.04	147.6	3948	4 240 000	1800	6.03 x 6.02	6.05	148.7	5408	.....
279	10.0	7.99	16.08	147.7	3690	4 000 000	1400	6.03 x 6.00	6.06	146.9	4875	.....
280	10.0	8.02	16.06	146.5	3667	3 860 000	1500	6.0 x 6.00	6.08	147.6	4876	.....
281	10.0	8.00	16.06	148.1	3956	4 360 000	1200	6.03 x 6.00	6.03	148.0	3606	.....
291	10.0	8.00	16.06	148.5	[1] 3979	4 500 000	1400	6.01 x 6.01	6.06	147.5	5056	.....
292	10.0	7.99	16.13	148.0	[1] 3989	4 780 000	1300	6.02 x 6.00	6.00	148.0	4927	.....
293	10.0	7.99	.....	.....	[1] 3989	4 160 000	1600	6.0 x 6.01	6.08	147.9	4113	.....
303	10.0	7.99	16.01	148.0	3904	4 400 000	1300	5.99 x 6.02	6.08	147.9	4250	.....
304	10.0	7.99	16.14	147.3	3690	4 500 000	1000	6.0 x 6.01	6.08	147.4	4331	.....
305	10.2	7.99	16.10	147.8	3789	4 340 000	1400	6.04 x 6.00	6.12	146.0	4344	.....
315	10.0	8.02	16.00	147.5	3781	4 500 000	1400	6.0 x 6.03	6.08	146.8	4000	.....
316	10.0	8.00	16.00	147.5	3912	3 780 000	1500	5.97 x 5.96	6.07	149.5	4727	.....
317	10.0	8.00	16.00	146.2	3803	4 400 000	1300	6.0 x 6.00	6.06	147.0	4503	.....
327	10.0	7.99	16.03	147.8	3890	4 580 000	900	6.03 x 6.05	6.00	148.0	4839	.....
328	10.0	8.00	16.14	147.5	3879	4 640 000	1300	6.02 x 6.05	6.00	148.3	4248	.....
329	10.0	7.98	15.95	148.4	3899	4 780 000	1400	6.02 x 6.00	6.00	148.5	4271	.....
Average.		.....	.....	.....	3778	4 310 000	1400	.....	.....	.....	4503	0.839

AGE, 52 WEEKS

246	10.0	8.00	16.18	147.6	4101	4 280 000	1800	6.03 x 6.06	6.02	146.3	4659	.....
247	10.0	8.01	16.15	146.7	4136	4 460 000	1700	6.03 x 6.15	5.99	147.3	4560	.....
248	10.0	8.01	16.08	146.3	3969	4 040 000	1700	6.09 x 6.01	6.01	148.3	4652	.....
270	9.8	8.00	16.10	147.4	4575	4 400 000	1600	6.03 x 6.00	6.00	147.3	5228	.....
271	10.0	8.00	16.20	148.0	4600	4 760 000	1500	6.03 x 6.07	5.98	149.0	5111	.....
272	10.0	8.01	16.04	148.8	4657	4 880 000	1700	6.09 x 6.00	5.99	147.5	5122	.....
282	10.0	7.99	15.98	147.7	4265	4 680 000	1700	6.00 x 6.02	6.00	147.0	5498	.....
283	10.0	7.99	16.03	147.8	4353	4 720 000	1700	6.08 x 6.03	5.97	147.0	4849	.....
284	10.0	8.01	16.18	146.2	4463	4 540 000	1600	6.02 x 6.02	6.01	147.9	4560	.....
294	10.0	7.99	16.10	149.0	4089	4 600 000	1800	6.00 x 6.08	6.00	147.5	4959	.....
295	10.0	8.00	15.98	148.8	4641	4 720 000	1500	5.98 x 6.01	5.99	150.5	4786	.....
296	10.0	7.98	16.06	149.5	5122	4 620 000	1600	5.96 x 6.10	6.00	150.0	5090	.....
306	10.2	8.00	16.14	147.6	4151	4 240 000	1500	5.98 x 5.99	6.00	148.2	5179	.....
307	10.0	8.01	16.12	148.0	4326	4 860 000	1500	6.00 x 6.03	6.00	150.3	5019	.....
308	10.0	8.01	16.08	147.5	4526	4 580 000	1600	6.02 x 6.07	6.00	148.2	5282	.....
309	10.0	8.03	16.06	145.3	4328	4 640 000	1500	5.99 x 6.09	6.00	146.5	4896	.....
310	10.0	8.01	16.16	145.6	4366	4 160 000	2100	6.02 x 6.07	6.03	147.0	4779	.....
311	10.2	8.02	16.10	145.3	4584	4 500 000	1700	5.92 x 6.02	6.03	148.7	4277	.....
330	10.0	8.00	16.04	148.3	4626	4 840 000	1700	6.00 x 6.10	6.00	146.6	5682	.....
331	10.0	8.01	16.20	146.5	3811	4 560 000	1700	6.05 x 6.01	6.02	147.5	5008	.....
332	10.0	7.98	16.10	147.9	4252	4 560 000	1500	5.97 x 6.12	6.05	147.6	4592	.....
Average.		.....	.....	.....	4378	4 550 000	1652	.....	.....	.....	4942	0.886

[1] Exceeded capacity of testing machine of 200 000 lbs., equivalent to given stress.

Table 35.—Compression Tests on Gravel Concrete of Medium Consistency Similar to that Used in Beams

[Proportions 1:2:4 by volume 1:2.01:4.10 by weight

AGE, 4 WEEKS

Register number	Percentage of water	Cylinders						Cubes				Stress ratio of cylinders to cubes
		Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	Initial modulus of elasticity	Yield point	Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	
		Diameter, inches	Length, inches					Base, inches	Height, inches			
333	9.5	8.03	16.17	143.8	3626	5 040 000	.....	6.07 x 6.04	6.11	141.8	3692	.....
334	9.5	8.07	16.16	141.9	3646	4 940 000	1300	6.01 x 6.00	6.08	142.8	4243	.....
335	9.0	7.99	16.07	144.5	3051	4 380 000	1200	6.04 x 6.05	6.12	140.1	4105	.....
345	9.0	8.10	16.18	140.1	2939	4 620 000	800	6.01 x 6.01	6.15	142.9	4098	.....
346	9.0	8.02	16.15	143.5	2573	4 360 000	900	6.18 x 5.97	6.15	139.9	3740	.....
347	9.0	8.01	16.20	143.1	2719	4 440 000	900	6.03 x 6.11	6.13	141.5	4228	.....
357	9.4	8.03	16.28	143.9	3735	4 720 000	1100	6.05 x 6.04	6.10	143.4	4576	.....
358	9.4	8.00	16.24	145.0	3386	4 620 000	1100	6.06 x 6.11	6.17	139.9	4144	.....
359	9.3	8.03	16.28	143.8	3199	4 740 000	1000	5.98 x 6.08	6.13	143.4	4106	.....
369	9.3	8.03	16.06	143.4	3268	5 020 000	1000	6.05 x 6.02	6.11	141.7	3763	.....
370	9.3	8.03	16.17	143.5	3091	4 620 000	1100	6.00 x 6.04	6.11	142.5	3804	.....
371	9.4	8.03	16.11	143 2	3389	4 800 000	1000	6.01 x 6.01	6.11	143.9	3465	.....
381	9.4	8.02	16.11	143.3	2652	3 880 000	900	.....	.....	.....	.....	.....
382	9.4	7.98	16.12	146.3	3079	4 400 000	1000	.....	.....	.....	.....	.....
383	9.4	8.02	16.05	144.6	3317	4 160 000	1100	.....	.....	.....	.....	.....
[1] 393	9.5	8.00	16.27	145.8	3232	4 000 000	600	.....	.....	.....	.....	.....
[2] 394	9.5	8.03	16.25	143.8	2861	4 410 000	1000	.....	.....	.....	.....	.....
[3] 395	9.8	8.01	16.10	144.1	2778	4 290 000	900	.....	.....	.....	.....	.....
[4] 405	9.8	8.00	16.13	147.1	3561	5 040 000	1200	.....	.....	.....	.....	.....
[5] 406	9.8	8.04	16.05	145.0	3211	5 720 000	1400	.....	.....	.....	.....	.....
[6] 407	9.8	8.03	16.11	145.1	3357	4 380 000	1200	.....	.....	.....	.....	.....
Average.		.....	.....	.....	3175	4 600 000	1050	.....	.....	.....	3997	0.794

AGE, 13 WEEKS

336	9.0	8.02	16.15	143.8	[2] 3959	4 015 000	2900	6.04 x 6.04	6.10	147.7	4975	.....
337	9.0	8.00	16.18	143.7	[2] 3979	4 780 000	2700	6.16 x 6.00	6.03	140.5	4690	.....
338	9.0	8.01	16.24	142.0	[2] 3969	4 640 000	1500	6.07 x 6.03	5.98	144.1	4795	.....
349	9.0	8.00	16.14	144.0	[2] 3979	4 960 000	1600	6.00 x 6.02	6.18	142.3	4606	.....
349	9.5	8.02	16.09	143.8	[2] 3959	3 980 000	2700	6.00 x 6.00	6.08	145.1	4596	.....
350	9.8	8.00	16.15	143.9	[2] 3979	4 760 000	1600	6.00 x 6.04	6.04	143.1	4527	.....
360	9.3	8.01	16.10	145.1	[2] 3969	4 920 000	2000	6.02 x 6.01	6.08	143.4	4552	.....
361	9.3	8.00	16.10	144.7	[2] 3979	4 100 000	1800	6.05 x 6.09	6.15	139.2	4180	.....
362	9.3	8.01	16.15	144.7	[2] 3969	5 360 000	1200	6.01 x 6.01	6.00	145.5	4283	.....
372	9.4	8.02	16.25	143.7	[2] 3959	4 560 000	2300	6.05 x 6.03	6.14	141.8	5003	.....
373	9.4	8.00	16.15	144.5	[2] 3979	4 680 000	2200	6.06 x 6.00	6.10	149.0	5052	.....
374	9.4	8.02	16.18	144.3	[2] 3959	4 900 000	2100	6.02 x 6.07	6.03	144.2	4909	.....
384	9.4	8.02	16.12	144.3	[2] 3959	4 680 000	2400	6.02 x 6.03	6.07	144.2	5018	.....
385	9.4	8.01	16.15	144.9	[2] 3969	4 800 000	2200	6.04 x 5.98	6.13	143.5	5382	.....
386	9.4	8.04	16.15	142.8	[2] 3939	4 720 000	2000	6.03 x 5.98	6.09	143.6	4906	.....
[3] 396	9.8	8.02	16.00	144.6	[2] 3959	4 740 000	1400	6.00 x 6.15	6.00	142.5	4808	.....
[4] 397	9.8	8.03	16.11	144.5	3929	4 680 000	2500	6.05 x 6.03	6.10	141.7	4863	.....
[5] 398	9.8	8.00	16.15	145.3	3780	4 540 000	2100	6.07 x 6.04	6.08	143.2	4655	.....
[6] 408	9.8	8.00	16.10	145.5	[2] 3979	4 470 000	2900	6.10 x 6.03	6.04	144.0	4872	.....
[7] 409	9.8	8.00	16.14	143.0	3596	4 310 000	2400	6.13 x 6.03	6.00	143.2	4171	.....
[1] 410	9.8	8.00	16.12	145.3	3978	4 450 000	2100	6.11 x 6.07	6.05	141.6	4460	.....
Average.		.....	.....	.....	(3821)	4 620 000	2100	.....	.....	.....	4729	0.846

[1] Proportions 1:2:4 by volume. 1:2.01:3.99 by weight.
[2] Exceeded capacity of testing machine of 200 000 lbs., equivalent to given stress.

Table 35.—Compression Tests on Gravel Concrete of Medium Consistency Similar to that Used in Beams—Continued

AGE, 26 WEEKS

Register number	Percentage of water	Cylinders						Cubes				Stress of cylinders to Cubes
		Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	Initial modulus of elasticity	Yield point	Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	
		Diameter, inches	Length, inches					Base, inches	Height, inches			
339	9.0	8.00	16.60	140.3	[2] 3979	5 440 000	1600	6.00 x 6.03	6.01	143.6	5063	.....
340	9.0	8.01	16.10	145.0	[2] 3969	5 060 000	1300	6.01 x 6.08	6.02	143.4	5405	.....
341	9.0	8.02	16.03	145.0	[2] 3959	5 420 000	1600	6.03 x 6.00	6.00	145.8	5153	.....
351	9.4	8.01	16.16	144.4	[2] 3969	5 260 000	1600	6.03 x 6.05	6.03	144.9	5091	.....
352	9.4	7.99	16.40	142.1	[2] 3989	5 040 000	1600	6.07 x 6.02	6.03	145.1	5044	.....
353	9.4	8.00	16.12	145.7	[2] 3979	5 420 000	1500	6.02 x 6.04	5.99	146.3	5406	.....
363	9.3	8.00	16.08	145.5	[2] 3979	4 940 000	1600	6.01 x 6.05	6.00	144.5	4959	.....
364	9.3	8.01	16.16	145.7	[2] 3969	4 940 000	2500	6.06 x 6.09	5.97	144.6	5196	.....
365	9.3	7.99	16.16	145.1	[2] 3989	4 900 000	1800	6.02 x 6.06	6.04	145.1	4939	.....
375	9.4	8.01	16.08	145.0	[2] 3969	5 200 000	1500	6.01 x 6.11	6.02	144.2	5163	.....
376	9.4	8.00	16.16	144.2	[2] 3979	5 200 000	1500	6.00 x 6.06	6.00	145.1	5388	.....
377	9.4	7.99	16.08	146.0	[2] 3989	4 940 000	1500	6.07 x 6.01	6.04	146.1	[2] 5483	.....
387	9.4	8.02	16.14	145.0	[2] 3959	5 080 000	1400	6.06 x 5.94	6.06	144.5	4648	.....
388	9.4	7.99	16.10	145.3	[2] 3989	5 500 000	1600	6.00 x 6.09	6.01	144.6	4803	.....
[1] 389	9.4	8.00	16.13	145.2	[2] 3979	6 080 000	1200	6.03 x 6.05	6.01	146.3	5154	.....
[1] 399	9.8	8.00	16.13	145.6	[2] 3979	4 940 000	1900	6.02 x 6.09	6.03	144.5	4148	.....
[1] 400	9.8	8.00	16.10	145.9	[2] 3979	5 320 000	1200	6.03 x 6.10	6.03	145.1	4111	.....
[1] 401	9.8	7.99	16.17	146.1	[2] 3989	4 960 000	1600	6.00 x 6.04	6.01	.....	4813	.....
[1] 411	9.9	7.99	16.02	146.0	[2] 3989	5 400 000	1400	6.00 x 6.05	6.04	143.8	3339	.....
[1] 412	9.9	8.00	16.12	145.8	[2] 3979	5 480 000	1400	6.00 x 6.04	6.01	144.8	3994	.....
[1] 413	9.9	8.00	16.15	144.9	[2] 3979	5 600 000	1400	6.02 x 6.01	6.03	144.5	3788	.....
Average.		.....	.....	.....	.....	5 240 000	1550	.....	.....	.....	4830	0.88

AGE, 52 WEEKS

342	9.0	8.00	16.12	145.5	5028	5 220 000	2100	6.11 x 5.97	6.03	144.4	5914	.....
343	9.0	8.00	16.16	145.2	5073	5 600 000	2000	6.03 x 6.02	6.01	144.5	5762	.....
344	9.0	8.00	16.06	145.0	5458	5 720 000	2200	6.01 x 6.13	6.01	143.5	5800	.....
354	9.4	7.99	16.04	146.6	5086	5 600 000	2200	6.00 x 6.08	5.99	144.3	5857	.....
355	9.4	8.00	16.24	145.3	4471	5 280 000	1800	6.00 x 6.12	6.00	144.2	5502	.....
356	9.4	7.98	16.06	145.7	5341	5 600 000	1500	6.00 x 6.08	6.01	144.8	4709	.....
366	9.3	7.99	16.12	145.7	5477	5 380 000	2100	6.13 x 6.02	6.01	143.7	5381	.....
367	9.3	7.98	16.16	146.2	4999	4 800 000	2800	6.08 x 6.00	5.99	145.8	5433	.....
368	9.3	7.99	16.18	146.0	5251	5 120 000	2400	6.01 x 6.09	6.04	145.7	5651	.....
378	9.4	8.00	16.05	146.7	5667	5 500 000	1800	6.03 x 6.01	6.00	155.0	6512	.....
379	9.4	8.01	16.13	145.1	5646	5 700 000	2300	6.00 x 6.05	6.00	156.7	6072	.....
380	9.4	8.00	16.02	145.7	5636	5 120 000	2300	6.00 x 6.09	5.99	146.0	6240	.....
390	9.4	8.00	16.07	145.9	5761	5 360 000	2200	5.99 x 6.10	6.03	144.2	5496	.....
391	9.4	7.98	16.06	146.1	4933	4 860 000	2600	6.00 x 6.10	6.00	144.6	5280	.....
[1] 392	9.4	8.02	16.10	145.3	4949	5 860 000	1900	6.01 x 6.07	6.03	144.4	5456	.....
[1] 402	9.8	7.99	16.13	146.4	4886	5 740 000	2400	6.03 x 6.12	5.99	144.6	5759	.....
403	9.8	7.98	16.07	147.3	5400	5 600 000	2200	6.00 x 6.12	6.02	145.7	5490	.....
404	9.8	7.99	16.17	146.9	4687	5 260 000	1900	6.00 x 6.13	5.99	147.1	5822	.....
414	9.9	8.00	16.10	145.6	5288	5 140 000	2400	6.02 x 6.04	6.00	144.5	4932	.....
415	9.9	8.00	16.08	146.4	5552	5 560 000	2000	6.01 x 6.12	6.00	144.9	5672	.....
416	9.9	8.00	16.10	146.0	5561	5 280 000	1700	6.00 x 6.04	6.01	145.9	5906	.....
Average.		.....	.....	.....	5245	5 395 000	2129	.....	.....	.....	5650	.928

[1] Proportions 1:2:4 by volume. 1:2.01:3,99 by weight.
[2] Exceeded capacity of testing machine of 200 000 lbs., equivalent to given stress.

Table 36.—Compression Tests on Cinder Concrete of Medium Consistency Similar to that Used in Beams

[Proportions 1 : 2 : 4 by volume. 1 : 2.01 : 1.97 by weight.]

AGE, 4 WEEKS

Register number	Percentage of water	Cylinders						Cubes				Stress ratio of cylinders to cubes
		Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	Initial modulus of elasticity	Yield point	Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	
		Diameter, inches	Length, inches					Base, inches	Height, inches			
417	19.2	7.99	16.08	121.6	1499	2 320 000	500	.....	.....	.....	.....	.....
418	19.2	8.06	16.21	118.3	1835	1 690 000	500	.....	.....	.....	.....	.....
419	19.3	8.01	16.14	119.5	1554	1 180 000	600	.....	.....	.....	.....	.....
429	18.9	8.04	16.11	120.4	1891	1 760 000	500	6.06 x 6.13	5.98	117.7	2417	.....
430	18.9	8.07	16.11	120.1	1918	1 820 000	500	6.02 x 6.00	6.04	119.8	2486	.....
431	18.9	8.08	16.10	119.6	1964	1 690 000	400	6.02 x 6.16	6.04	118.7	2523	.....
441	18.9	8.10	16.00	115.8	1514	1 190 000	500	6.05 x 6.05	6.10	117.1	2161	.....
442	18.9	8.03	16.10	117.9	1575	1 620 000	500	6.05 x 6.05	6.13	115.6	2195	.....
443	18.8	8.00	15.95	119.6	1577	1 600 000	600	5.98 x 6.08	6.04	117.2	2258	.....
453	18.8	8.03	16.16	118.5	1593	1 615 000	500	.....	.....	.....	.....	.....
454	18.8	8.04	16.30	117.5	1576	1 645 000	300	.....	.....	.....	.....	.....
455	18.9	8.01	16.18	117.9	1620	1 640 000	500	.....	.....	.....	.....	.....
465	18.9	8.01	16.25	116.1	1572	1 535 000	400	6.01 x 6.02	6.11	117.3	2170	.....
466	18.9	8.00	16.31	116.7	1534	1 435 000	400	6.07 x 6.04	6.09	116.1	2046	.....
467	18.9	8.01	16.16	119.1	1532	1 660 000	400	6.03 x 6.05	6.07	117.1	2121	.....
477	18.9	8.04	16.05	118.5	1614	1 660 000	400	6.05 x 5.97	6.15	116.7	2139	.....
478	18.9	8.02	16.07	119.2	1682	1 460 000	500	6.07 x 6.09	6.15	112.2	.....	.....
479	18.9	8.05	16.23	115.8	1603	1 540 000	400	6.05 x 6.03	6.08	114.0	1990	.....
489	18.9	8.03	16.05	116.9	1629	1 530 000	500	6.02 x 6.02	6.09	117.5	1956	.....
490	18.9	8.03	16.04	118.1	1710	1 680 000	300	6.04 x 6.03	6.12	116.3	1850	.....
491	18.9	8.02	16.05	118.3	1589	1 620 000	500	6.01 x 6.07	6.10	115.5	1849	.....
Average.		.....	.....	.....	1647	1 610 000	450	.....	.....	.....	2154	0.763

AGE, 13 WEEKS

420	19.3	8.01	16.05	118.8	2260	1 700 000	900	6.00 x 6.01	6.02	117.4	2773	.....
421	19.5	8.00	16.05	120.2	2399	1 930 000	700	6.07 x 6.02	6.10	119.2	2442	.....
422	19.5	8.00	16.13	119.4	2322	1 930 000	500	6.04 x 6.03	6.11	117.5	2843	.....
432	18.9	8.00	16.16	121.5	2445	1 880 000	1100	6.05 x 6.02	6.18	118.0	2965	.....
433	18.9	8.02	16.01	120.5	2426	1 800 000	1000	6.04 x 6.04	6.18	118.9	2784	.....
434	18.9	8.00	16.09	119.4	2259	1 790 000	700	6.02 x 6.05	6.07	119.1	2858	.....
444	18.8	8.01	16.09	119.2	2147	1 730 000	900	6.03 x 6.03	6.10	115.9	2676	.....
445	18.8	8.00	16.05	120.2	2110	1 720 000	900	6.05 x 6.00	6.07	116.7	2590	.....
446	18.8	8.02	16.11	118.6	1981	1 870 000	900	6.01 x 6.03	6.02	120.7	2667	.....
456	18.9	8.00	16.10	119.1	2305	1 810 000	800	6.13 x 6.03	6.04	114.2	2166	.....
457	18.9	7.99	16.23	121.6	2266	1 910 000	900	5.99 x 6.00	6.01	120.0	1842	.....
458	18.9	8.00	16.11	119.6	2185	1 820 000	900	6.04 x 6.04	6.01	121.2	2423	.....
468	18.9	8.02	16.06	117.9	2203	1 740 000	1000	6.02 x 6.00	6.04	117.8	2556	.....
469	18.9	8.01	16.23	118.6	2180	1 730 000	900	6.02 x 6.01	6.09	116.7	2419	.....
470	18.9	8.01	16.15	119.2	2201	1 920 000	500	6.01 x 6.03	6.02	119.8	2541	.....
480	18.9	8.01	16.03	118.2	2150	1 850 000	600	6.04 x 6.08	6.04	115.9	2568	.....
481	18.9	8.00	16.13	118.3	2108	1 800 000	700	6.05 x 5.99	5.98	118.7	2644	.....
482	18.9	8.01	16.18	118.2	2121	1 840 000	600	6.06 x 6.02	5.97	119.0	2452	.....
492	18.9	8.01	16.01	119.9	2107	1 760 000	600	6.01 x 6.00	6.10	116.9	2516	.....
493	18.9	8.00	16.10	120.1	.....	1 740 000	700	6.01 x 6.02	6.10	115.5	2531	.....
494	18.9	8.00	16.02	118.6	2169	1 920 000	800	5.98 x 6.01	6.05	117.3	2739	.....
Average.		.....	.....	.....	2217	1 820 000	800	.....	.....	.....	2571	0.862

Table 36.—Compression Tests on Cinder Concrete of Medium Consistency Similar to that Used in Beams—Continued.

AGE, 26 WEEKS

Register number	Percentage of water	Cylinders						Cubes				Stress of cylinders to Cubes
		Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	Initial modulus of elasticity	Yield point	Dimensions		Weight, lbs. per cu. ft.	Ultimate strength, lbs. per sq. in.	
		Diameter, inches	Length, inches					Base, inches	Height, inches			
423	19.5	8.00	16.15	122.0	2792	2 240 000	800	6.01 x 6.08	6.00	120.2	2831	.....
424	19.5	8.02	16.26	121.6	2746	2 300 000	900	6.00 x 6.05	6.00	124.1	3486	.....
425	19.5	8.00	16.04	123.0	2586	2 200 000	1000	6.00 x 6.11	6.01	121.1	3021	.....
435	18.9	8.01	16.16	120.0	2778	2 320 000	900	6.04 x 6.07	6.00	120.8	2403	.....
436	18.9	8.00	16.14	121.0	2714	2 080 000	1000	6.05 x 5.93	6.09	121.0	2609	.....
437	18.9	7.99	16.12	120.8	2546	2 080 000	800	6.02 x 6.06	6.03	119.8	2084	.....
447	18.8	8.00	16.20	119.5	2359	2 060 000	1000	6.03 x 6.25	6.04	116.3	2778	.....
448	18.8	8.01	16.32	119.5	2371	2 250 000	800	6.00 x 6.28	6.00	118.5	2857	.....
449	18.8	8.02	16.12	120.0	2344	2 000 000	900	6.03 x 6.26	5.98	118.6	2443	.....
459	18.9	8.00	16.42	115.8	2591	2 130 000	900	6.03 x 6.03	6.02	117.4	3210	.....
460	18.9	8.01	16.38	117.1	2546	2 250 000	1100	6.03 x 6.11	6.01	119.5	2902	.....
461	18.9	8.02	16.47	116.8	2486	2 380 000	1200	6.06 x 6.00	5.99	118.1	2866	.....
471	18.9	7.99	16.02	119.0	2706	2 040 000	1000	6.08 x 6.02	6.03	117.5	2485	.....
472	18.9	8.00	16.02	119.9	2615	1 880 000	900	6.03 x 6.05	6.02	118.5	2166	.....
473	18.9	7.99	16.02	119.4	2595	1 830 000	900	6.00 x 6.00	6.01	114.3	1750	.....
483	18.9	8.00	16.14	119.3	2284	2 120 000	900	6.02 x 5.98	6.04	117.3	2880	.....
484	18.9	8.02	16.04	117.8	2344	2 080 000	900	6.02 x 6.04	6.02	118.4	2862	.....
485	18.9	8.01	16.01	120.5	2187	2 040 000	700	6.06 x 6.04	6.08	117.5	2903	.....
495	18.9	8.00	16.04	118.7	2563	1 990 000	900	6.00 x 6.08	6.00	118.4	2557	.....
496	18.9	8.00	16.08	118.9	2388	1 960 000	1000	6.00 x 6.04	6.20	115.4	2775	.....
497	18.9	8.02	16.04	118.5	2482	2 180 000	900	5.99 x 6.04	5.98	120.9	2879	.....
Average.		.....	.....	.....	2525	2 120 000	900	.....	.....	.....	2702	0.935

AGE, 52 WEEKS

426	19.5	8.00	16.04	122.7	2941	2 350 000	1000	6.01 x 6.02	6.03	119.8	3457	.....
427	18.9	8.00	16.10	121.4	2945	2 020 000	1000	6.00 x 6.09	6.02	120.8	3040	.....
428	18.9	8.00	16.12	120.2	2947	2 290 000	900	6.00 x 6.05	6.02	121.0	3054	.....
438	18.9	8.00	16.16	119.1	2886	2 090 000	800	5.99 x 6.00	6.00	119.2	3454	.....
439	18.9	8.00	16.16	118.6	2958	2 170 000	1100	5.99 x 6.10	6.00	118.7	3236	.....
440	18.9	7.99	16.15	120.6	2838	2 000 000	1200	6.01 x 6.04	6.02	120.1	3269	.....
450	18.8	8.00	16.11	119.8	2685	2 240 000	1200	6.25 x 6.03	5.97	118.1	2793	.....
451	18.9	7.99	16.14	121.5	2493	2 080 000	1200	6.28 x 5.99	6.00	118.7	2637	.....
452	18.9	8.00	16.10	119.6	2680	2 340 000	900	5.99 x 6.26	5.99	119.7	2669	.....
462	18.9	8.02	16.08	118.7	2767	2 030 000	1100	6.01 x 6.01	5.96	117.9	3108	.....
463	18.9	8.01	16.18	117.9	2610	1 980 000	1100	6.04 x 6.00	6.00	119.7	3158	.....
464	18.9	7.98	16.11	118.6	2678	1 990 000	.....	6.02 x 6.01	6.01	119.7	2948	.....
474	18.9	8.00	16.12	119.7	2685	1 910 000	1400	5.99 x 6.07	6.03	115.3	3578	.....
475	18.9	8.00	16.10	120.0	2783	2 170 000	1000	6.03 x 6.02	6.00	120.1	3269	.....
476	18.9	8.01	16.14	119.0	2778	2 090 000	1000	5.97 x 6.10	5.99	118.9	2999	.....
486	18.9	7.98	16.09	120.5	2766	2 060 000	1300	6.00 x 6.02	6.02	118.3	3214	.....
487	18.9	7.98	16.11	120.4	2600	2 070 000	1200	6.00 x 6.05	6.01	116.8	2908	.....
488	18.9	8.02	16.08	118.3	2655	2 080 000	800	6.00 x 6.02	5.98	119.0	2896	.....
498	18.9	8.01	16.22	118.7	2877	2 150 000	1100	5.99 x 6.03	6.03	119.0	2912	.....
499	18.9	8.02	16.17	120.6	2771	1 950 000	1200	5.98 x 6.05	6.00	120.5	3448	.....
500	18.9	8.01	16.12	119.1	2640	2 180 000	1000	6.00 x 6.08	6.02	122.0	3407	.....
Average.		.....	.....	.....	2761	2 114 000	1075	.....	.....	.....	3117	.886

Appendix I—Log Sheets for one Representa-

1:2:4 GRANITE CONCRETE

Total Load, lbs.	Cylinder No. 162 Granite 4 weeks		Cylinder No. 244 Granite 13 weeks		Cylinder No. 170 Granite 26 weeks		Cylinder No. 173 Granite 52 weeks	
	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.
250							5	
5000	99	20	99	25	100	21	100	21
10 000	198	30	198	50	199	42	199	42
15 000	297	30	297	71	298	67	299	63
20 000	396	50	396	92	398	83	399	83
25 000	495	70	495	115	497	100	499	104
30 000	594	100	594	138	597	125	598	125
35 000	693	130	693	158	696	146	698	145
40 000	792	150	792	182	796	163	798	167
45 000	891	180	891	204	895	188	897	188
50 000	990	220	990	228	995	217	997	208
55 000	1089	240	1089	250	1094	238	1097	229
60 000	1188	270	1188	271	1194	258	1197	250
65 000	1287	300	1287	294	1293	283	1296	271
70 000	1386	330	1386	315	1392	304	1396	292
75 000	1485	370	1485	346	1492	333	1496	313
80 000	1584	400	1584	371	1591	354	1595	338
85 000	1683	430	1683	396	1691	375	1695	358
90 000	1782	480	1782	413	1790	400	1795	379
95 000	1881	530	1881	433	1890	425	1894	404
100 000	1980	580	1980	457	1989	450	1994	429
105 000	2079	650	2079	483	2089	483	2094	454
110 000	2178	710	2178	513	2188	508	2194	479
115 000	2276	760	2276	538	2288	538	2293	504
120 000	2375	830	2375	563	2387	563	2393	529
125 000	2474	920	2474	588	2487	592	2493	554
130 000			2573	611	2586	621	2592	579
135 000			2672	646	2686	654	2692	604
140 000			2771	675	2785	675	2792	629
145 000			2870	700	2885	713	2892	658
150 000			2969	738	2984	750	2991	688
155 000			3068	783	3084	779	3091	717
160 000			3167	817	3183	817	3191	742
165 000			3266	867	3283	854	3290	771
170 000			3365	896	3382	896	3390	804
175 000			3464	933	3482	933	3490	838
180 000			3563	988	3581	988	3590	871
185 000			(1)		(1)		3689	904
190 000							3789	938
195 000							3889	971
200 000							3988	1004
205 000							4088	1046
210 000							4188	1092
215 000							4288	1138
220 000							4387	1183
225 000							4487	1233
230 000							4587	1288
235 000							4686	1342
240 000							4786	1413
245 000							4886	1488

[1] Ultimate load exceeded the capacity of the testing machine (200 000 lb.=3969 lb. per sq. in.).

tive Cylinder for each Age and Aggregate

1:2:4 GRAVEL CONCRETE

Cylinder No. 359 Gravel 4 weeks		Cylinder No. 338 Gravel 13 weeks		Cylinder No. 351 Gravel 26 weeks		Cylinder No. 366 Gravel 52 weeks		Total load, lbs.
Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	
				5		5		250
99	20	99	50	99	25	100	21	5000
197	30	198	79	198	42	199	38	10 000
296	50	298	108	298	63	299	50	15 000
395	80	397	138	397	83	399	67	20 000
494	100	496	154	496	100	499	88	25 000
592	130	595	171	595	121	598	104	30 000
691	140	695	196	695	142	698	125	35 000
790	160	794	208	794	154	798	146	40 000
889	180	893	233	893	171	897	163	45 000
987	210	992	254	992	192	997	179	50 000
1086	230	1092	267	1092	208	1097	192	55 000
1185	250	1191	296	1191	233	1197	213	60 000
1284	280	1290	317	1290	250	1296	235	65 000
1382	310	1389	338	1389	271	1396	254	70 000
1481	330	1488	358	1488	288	1496	275	75 000
1580	350	1588	379	1588	308	1595	288	80 000
1678	380	1687	404	1687	325	1695	304	85 000
1777	400	1786	425	1786	354	1795	321	90 000
1876	440	1885	450	1885	375	1894	346	95 000
1975	470	1984	475	1984	392	1994	367	100 000
2074	500	2084	500	2084	413	2094	388	105 000
2172	550	2183	525	2183	433	2194	408	110 000
2271	580	2282	550	2282	454	2293	429	115 000
2370	620	2381	575	2381	479	2393	450	120 000
2468	650	2481	600	2481	500	2493	467	125 000
2567	700	2580	633	2580	521	2592	488	130 000
		2679	667	2679	546	2692	508	135 000
		2778	700	2778	575	2792	533	140 000
		2877	733	2877	600	2892	550	145 000
		2977	767	2977	621	2991	571	150 000
		3076	800	3076	650	3091	600	155 000
		3175	833	3175	679	3191	625	160 000
		3274	863	3274	708	3290	642	165 000
		3374	896	3374	738	3390	671	170 000
		3473	933	3473	771	3490	688	175 000
		3572	983	3572	804	3590	708	180 000
		3671	1038	3671	838	3689	733	185 000
		3770	1104	3770	871	3789	754	190 000
		3870	1225	3870	913	3889	775	195 000
		3969	1375	3969	971	3988	804	200 000
		(1)		(1)		4088	833	205 000
						4188	863	210 000
						4288	896	215 000
						4387	925	220 000
						4487	954	225 000
						4587	983	230 000
						4686	1021	235 000
						4786	1058	240 000
						4886	1092	245 000
						4966	1142	250 000
						5085	1192	255 000
						5185	1267	260 000

[1] Ultimate load exceeded the capacity of the testing machine (200 000 lb.=3969 lb. per sq. in.).

Appendix I—Log Sheets for one Representative

1:2:4 LIMESTONE CONCRETE—Continued

Total Load, lbs.	Cylinder No. 274 Limestone 4 weeks		Cylinder No. 264 Limestone 13 weeks		Cylinder No. 305 Limestone 26 weeks		Cylinder No. 283 Limestone 52 weeks	
	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.
250					5		5	
5000	99		99	33	100	17	100	21
10 000	198	30	198	67	199	38	199	42
15 000	298	60	297	100	299	58	299	58
20 000	397	80	396	129	399	83	399	83
25 000	496	110	495	146	499	108	499	104
30 000	595	130	594	179	598	125	598	125
35 000	695	160	693	204	698	150	698	146
40 000	794	180	792	225	798	175	798	171
45 000	893	210	891	246	898	196	897	192
50 000	992	240	990	275	997	225	997	213
55 000	1092	270	1089	304	1097	246	1097	233
60 000	1191	310	1188	329	1197	275	1197	254
65 000	1290	340	1287	358	1296	292	1296	275
70 000	1389	350	1386	388	1396	317	1396	296
75 000	1488	380	1485	417	1496	350	1496	317
80 000	1587	430	1584	450	1595	379	1595	338
85 000	1687	480	1683	483	1695	408	1695	358
90 000	1786	520	1782	508	1795	433	1795	383
95 000	1885	560	1881	542	1895	463	1894	408
100 000	1985	600	1980	575	1994	492	1994	458
105 000			2079	608	2094	529	2094	463
110 000			2178	650	2194	554	2194	492
115 000			2276	688	2294	592	2293	521
120 000			2375	717	2393	621	2393	550
125 000			2474	750	2493	658	2493	575
130 000			2573	800	2593	696	2592	604
135 000			2672	842	2692	729	2692	633
140 000			2771	888	2792	767	2792	657
145 000			2870	942	2892	808	2892	700
150 000			2969	988	2992	854	2991	733
155 000			3068	1050	3191	896	3091	771
160 000			3167	1113	3211	950	3191	804
165 000			3266	1175	3291	1004	3290	842
170 000			3365	1242	3391	1063	3390	879
175 000					3490	1121	3490	921
180 000					3590	1179	3590	963
185 000					3690	1258	3689	1004
190 000					3789	1358	3789	1050
195 000							3889	1096
200 000							3988	1146
205 000							4088	1217

Cylinder for each Age and Aggregate—Continued

1:2:4 CINDER CONCRETE—Continued

Cylinder No. 455 Cinder 4 weeks		Cylinder No. 456 Cinder 13 weeks		Cylinder No. 459 Cinder 26 weeks		Cylinder No. 475 Cinder 52 weeks		Total load, lbs.
Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	Unit Stress, lb. per sq. in.	Deformation, millionths of in. per in.	
				5		5		250
99	50	100	42	100	46	99	46	5000
198	110	199	83	199	88	199	88	10 000
298	170	298	133	298	133	298	133	15 000
397	240	398	188	398	175	398	183	20 000
496	300	497	246	497	217	497	225	25 000
595	380	597	308	597	267	597	271	30 000
695	460	696	354	696	313	696	313	35 000
794	570	796	429	796	363	796	363	40 000
893	700	895	483	895	413	895	408	45 000
992	770	995	538	995	463	995	458	50 000
1092	900	1094	592	1094	513	1094	504	55 000
1191	1050	1194	663	1194	567	1194	558	60 000
1290	1230	1293	738	1293	625	1293	617	65 000
1389	1600	1392	804	1392	683	1392	671	70 000
		1492	892	1492	746	1492	725	75 000
		1591	971	1591	808	1591	779	80 000
		1691	1071	1691	879	1691	833	85 000
		1790	1188	1790	950	1790	900	90 000
		1890	1317	1890	1021	1890	963	95 000
		1989	1463	1989	1108	1989	1029	100 000
		2089	1650	2089	1196	2089	1104	105 000
		2188	1908	2188	1288	2188	1188	110 000
				2288	1396	2288	1275	115 000
				2387	1529	2387	1367	120 000
				2487	1671	2487	1483	125 000
				2586	1904	2586	1613	130 000
						2685	1775	135 000

Appendix II—Log Sheets of Concrete Beams

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 162					
0	24.85	30	24	55.3	0.005
500	39.85	48	39	55.4	.015
1000	54.85	66	53	55.4	.025
1500	69.85	82	65	55.9	.030
2000	84.85	103	82	55.7	.035
2500	99.85	127	94	57.5	.050
2750	107.35	139	103	57.5	.055
3000	114.85	150	111	57.5	.060
3250	122.35	159	130	55.1	.070
3500	129.85	178	166	51.8	.075
3750	137.35	274	441	38.3	.135
4000	144.85	307	528	36.7	.165
4250	152.35	334	612	35.3	.205
4500	159.85	369	704	34.4	.235
5000	174.85	424	868	32.8	.285
5300	189.85	472	1014	31.8	.325
5900	201.85	.....	.....	.....	.....
5100	177.85	.....	1561	.....	.425
BEAM 163					
0	25.47	29	31	48.3	0.015
500	40.47	47	41	53.6	.025
1000	55.47	61	53	53.4	.035
1500	70.47	75	70	51.8	.045
2000	85.47	94	87	51.9	.055
2500	100.47	110	103	51.6	.065
3000	115.47	129	125	50.7	.065
3250	122.97	144	140	50.7	.075
3500	130.47	166	173	49.0	.085
3750	137.97	225	369	37.8	.125
4000	145.47	258	489	34.6	.155
4250	152.97	281	583	32.5	.165
4500	160.47	309	674	31.4	.185
4750	167.97	330	769	30.0	.215
5000	175.47	366	885	29.2	.245
5250	182.97	392	956	29.1	.255
5500	190.47	409	1019	28.7	.265
5750	197.97	433	1085	28.5	.285
6000	205.47	451	1156	28.1	.325
6250	212.97	471	1238	27.6	.345
6500	220.47	495	1313	27.4	.355
6750	227.97	516	1415	26.7	.385
7000	235.47	.....	1492	.....	.395
BEAM 164					
0	26.09	23	21	52.5	0.005
500	41.09	36	41	46.6	.015
1000	56.09	49	55	47.2	.020
1500	71.09	62	70	46.8	.025
2000	86.09	82	84	49.5	.035
2500	101.09	95	99	48.9	.040
3000	116.09	111	121	47.8	.050
3250	123.59	122	137	47.1	.055
3500	131.09	131	185	41.4	.065
3750	138.59	163	256	38.9	.085
4000	146.09	191	344	35.7	.110
4250	153.59	243	550	30.6	.145
4500	161.09	264	641	29.2	.170
4750	168.59	285	737	27.9	.195
5000	176.09	306	815	27.3	.220
5250	183.59	326	896	26.7	.245
5500	191.09	346	974	26.2	.260
5750	198.59	368	1062	25.7	.275
6000	206.09	389	1140	25.5	.305
6250	213.59	406	1200	25.3	.325
6500	221.09	.....	.....	.....	.....

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 174					
0	25.47	61	50	54.8	0.015
500	40.47	77	72	51.8	.025
1000	55.47	105	109	49.0	.035
1500	70.47	129	137	48.6	.045
2000	85.47	160	164	49.4	.055
2500	100.47	193	193	50.0	.065
3000	115.47	222	224	49.8	.080
3500	130.47	249	260	49.0	.095
4000	145.47	279	301	48.1	.105
4500	160.47	314	359	46.6	.115
5000	175.47	352	458	43.4	.155
5500	190.47	388	540	41.8	.175
6000	205.47	431	619	41.0	.215
6500	220.47	467	691	40.3	.245
7000	235.47	505	769	39.6	.265
7500	250.47	544	845	39.1	.295
8000	265.47	587	930	38.7	.330
8500	280.47	626	997	38.6	.360
9000	295.47	665	1068	38.4	.385
9300	304.47	.....	(1135)	.....	.415
7500	250.47	797	1979	28.7	.465
BEAM 175					
0	25.26	37	27	58.0	0.010
800	49.26	62	53	53.8	.015
1600	73.26	92	75	55.2	.025
2000	85.26	109	87	55.6	.035
2500	100.26	127	108	54.0	.045
3000	115.26	147	130	53.0	.065
3500	130.26	184	183	50.2	.070
3750	137.76	245	321	43.3	.095
4000	145.26	256	349	42.3	.110
4250	152.76	285	402	41.5	.125
4500	160.26	311	468	39.9	.145
4750	167.76	333	504	39.8	.165
5000	175.26	357	556	39.1	.180
5250	182.76	375	602	38.4	.195
5500	190.26	392	639	38.0	.205
6000	205.26	437	750	36.8	.240
6500	220.26	476	841	36.1	.275
7000	235.26	521	930	35.9	.295
7500	250.26	564	1026	35.5	.335
8000	265.26	609	1109	35.4	.365
8500	280.26	652	1198	35.2	.405
8750	287.76	677	1234	35.4	.425
8900	292.26	.....	.....	.....	.445
BEAM 176					
0	25.47	37	24	60.7	0.010
500	40.47	50	39	56.4	.020
1000	55.47	69	53	56.6	.030
1500	70.47	88	65	57.4	.030
2000	85.47	105	82	56.2	.040
2500	100.47	126	101	55.6	.045
3000	115.47	146	121	54.7	.055
3500	130.47	178	154	53.6	.070
3750	137.97	193	191	50.3	.080
4000	145.47	221	234	48.5	.090
4250	152.97	254	309	45.1	.100
4500	160.47	291	403	41.9	.120
4750	167.97	331	453	42.2	.140
5000	175.47	362	509	41.5	.160
5500	190.47	407	602	40.4	.190
6000	205.47	443	694	39.0	.220
6500	220.47	500	786	38.9	.260
7000	235.47	538	875	38.1	.240
7500	250.47	581	962	37.7	.300
8000	265.47	619	1065	36.8	.330
8500	280.47	685	1212	36.1	.....
8750	287.97	717	1332	35.0	.....
9000	295.47	.....	1431	.....	.....

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 186					
0	25.68	26	21	55.7	0.010
800	49.68	50	38	57.0	.020
1600	73.68	75	56	57.1	.030
2480	97.68	100	77	56.5	.040
3200	121.68	130	101	56.2	.050
3600	133.68	148	118	55.7	.060
4000	145.68	173	150	53.6	.070
4400	157.68	195	179	52.1	.080
4800	169.68	232	234	49.8	.090
5200	181.68	276	287	49.0	.100
5600	193.68	303	349	46.4	.130
6000	205.68	334	410	44.9	.150
6500	220.68	371	479	43.6	.160
7000	235.68	400	557	41.8	.190
8000	265.68	466	670	41.0	.230
9000	295.68	530	805	39.7	.260
10 000	325.68	591	930	38.9	.300
11 000	355.68	648	1045	37.8	.350
11 500	370.68	681	1128	37.7	.380
12 000	385.68	712	1190	37.4	.395
12 500	400.68	744	1262	37.1	.420
13 000	415.68	772	1320	36.9	.440
13 230	424.08	.....	1340	.....	.460
BEAM 187					
0	25.26	19	17	52.5	0.010
1000	55.26	53	43	55.1	.020
2000	85.26	88	70	55.7	.030
3000	115.26	128	106	54.2	.050
3500	130.26	154	133	53.7	.060
4000	145.26	181	164	52.5	.070
4500	160.26	217	222	49.4	.080
5000	175.26	260	311	45.5	.110
5500	190.26	297	386	43.5	.130
6000	205.26	332	462	41.8	.165
7000	235.26	400	621	39.2	.210
8000	265.26	467	768	37.8	.260
9000	295.26	533	930	36.4	.310
10 000	325.26	607	1038	36.9	.350
11 000	355.26	682	1191	36.4	.400
11 650	374.76	.....	1369	.....	.450
10 000	325.26	781	1701	30.5	.470
BEAM 188					
0	25.68	34	31	52.5	0.005
1000	55.68	75	85	46.9	.025
2000	85.68	105	109	49.0	.035
3000	115.68	147	144	50.4	.050
3500	130.68	165	159	51.0	.060
4000	145.68	190	185	50.6	.075
4500	160.68	215	224	49.0	.085
5000	175.68	251	292	46.2	.105
5500	190.68	284	378	42.9	.125
6000	205.68	321	455	41.3	.155
7000	235.68	389	597	39.5	.205
8000	265.68	451	750	37.6	.245
9000	295.68	515	903	36.3	.295
10 000	325.68	581	1022	36.3	.335
11 000	355.68	644	1157	35.8	.395
11 500	370.68	681	1232	35.6	.425
12 000	385.68	727	1328	35.4	.445
12 460	399.48	.....	1409	.....	.465
10 800	349.68	781	1821	30.0	.495

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 198					
0	26.09	39	24	62.0	0.010
1000	56.09	66	53	55.4	.020
2000	86.09	100	75	57.1	.030
3000	116.09	135	104	56.5	.050
3500	131.09	159	126	55.8	.060
4000	146.09	181	162	52.8	.070
4500	161.09	206	200	50.8	.080
5000	176.09	236	255	47.9	.100
5500	191.09	277	335	45.2	.120
6000	206.09	314	419	42.8	.140
6500	221.09	350	491	41.6	.160
7000	236.09	390	566	40.8	.190
8000	266.09	450	689	39.5	.230
9000	296.09	514	809	38.9	.270
10 000	326.09	576	916	38.6	.320
11 000	356.09	651	1043	38.4	.360
12 000	386.09	720	1154	38.4	.410
13 000	416.09	798	1280	38.4	.450
13 500	431.09	839	1344	38.4	.470
14 000	446.09	.....	1429	.....	.....
11 900	383.09	889	1897	31.9	.510
12 500	401.09	1038	2860	25.6	.630
BEAM 199					
0	26.09	30	29	50.8	0.010
1000	56.09	52	56	52.5	.020
2000	86.09	93	84	52.5	.030
3000	116.09	127	115	52.5	.050
3500	131.09	152	140	52.0	.060
4000	146.09	169	169	50.0	.070
4500	161.09	202	224	47.5	.080
5000	176.09	230	263	46.6	.095
5500	191.09	264	328	44.6	.110
6000	206.09	300	405	42.6	.140
6500	221.09	342	482	41.5	.160
7000	236.09	376	545	40.8	.180
8000	266.09	447	674	39.9	.220
9000	296.09	508	798	38.9	.260
10 000	326.09	581	920	38.7	.300
11 000	356.09	651	1051	38.3	.350
12 000	386.09	724	1178	38.1	.400
13 000	416.09	799	1311	37.9	.440
13 500	431.09	850	1390	37.9	.....
14 000	446.09	.....	1497	.....	.....
12 300	395.09	932	2041	31.3	.....
BEAM 200					
0	26.09	37	27	58.0	0.015
1000	56.09	82	62	57.0	.030
2000	86.09	116	84	58.0	.045
3000	116.09	146	111	56.8	.055
3500	131.09	163	126	56.5	.065
4000	146.09	185	150	55.2	.075
4500	161.09	211	188	52.9	.085
5000	176.09	243	236	50.7	.100
6000	206.09	317	379	45.5	.135
7000	236.09	388	530	42.3	.175
8000	266.09	463	653	41.5	.205
9000	296.09	525	778	40.3	.255
10 000	326.09	595	903	39.7	.295
11 000	356.09	657	1022	39.1	.345
12 000	386.09	723	1159	38.4	.390
13 000	416.09	794	1308	37.8	.445
13 500	431.09	831	1386	37.5	.465
13 750	438.59	.....	1412	.....	.....
13 300	425.09	854	1474	36.7	.....
12 100	389.09	900	1921	31.9	.525

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 210					
0	25.88	26	21	55.7	0.005
1500	70.88	74	58	55.9	.025
2500	100.88	105	84	55.7	.035
3500	130.88	143	120	54.4	.045
4000	145.88	168	149	53.0	.060
4500	160.88	195	179	52.1	.075
5000	175.88	225	212	51.5	.085
5500	190.88	257	255	50.2	.095
6000	205.88	293	311	48.5	.115
7000	235.88	359	419	46.1	.155
8000	265.88	421	521	44.7	.195
9000	295.88	487	626	43.7	.235
10 000	325.88	552	744	42.6	.275
11 000	355.88	616	858	41.8	.305
12 000	385.88	679	971	41.2	.345
13 000	415.88	744	1080	40.8	.375
14 000	445.88	798	1178	40.4	.425
15 000	475.88	877	1282	40.6	.465
15 500	490.88	927	1366	40.4	.485
15 860	501.68	.....	1477	.....	.....
16 000	505.88	.....	1559	.....	.555
14 300	454.88	1050	2010	34.3	.555
BEAM 211					
0	25.68	27	31	46.5	0.005
1500	70.68	75	65	53.6	.015
2500	100.68	102	91	52.8	.030
3500	130.68	138	123	52.9	.045
4000	145.68	166	156	51.6	.055
4500	160.68	188	191	49.6	.065
5000	175.68	213	229	48.2	.080
5500	190.68	254	284	47.2	.095
6000	205.68	282	340	45.3	.115
7000	235.68	337	458	42.4	.155
8000	265.68	405	576	41.3	.195
9000	295.68	465	687	40.3	.235
10 000	325.68	530	807	39.6	.275
11 000	355.68	602	923	39.5	.315
12 000	385.68	651	1039	38.9	.355
13 000	415.68	731	1161	38.6	.405
14 000	445.68	814	1277	38.9	.445
15 000	475.68	904	1462	38.2	.495
15 500	490.58	.....	1538	.....	.535
15 000	475.68	963	1617	37.3	.....
15 400	487.68	.....	.....	.....	.555
14 900	472.68	1006	1773	36.2	.565
BEAM 212					
0	25.47	34	27	55.8	0.015
1500	70.47	83	68	54.8	.035
2500	100.47	119	96	55.3	.050
3500	130.47	158	128	55.3	.065
4000	145.47	188	156	54.7	.075
4500	160.47	217	191	53.2	.095
5000	175.47	252	239	51.3	.105
5500	190.47	289	285	50.3	.125
6000	205.47	329	335	49.6	.145
6500	220.47	369	409	47.4	.175
7000	235.47	405	470	46.3	.205
8000	265.47	468	588	44.3	.245
9000	295.47	534	709	43.0	.285
10 000	325.47	612	824	42.6	.335
11 000	355.47	671	944	41.5	.365
12 000	385.47	740	1056	41.2	.405
13 000	415.47	817	1171	41.1	.455
14 000	445.47	901	1311	40.8	.505
15 000	475.47	1056	1614	39.6	.595
15 100	478.47	.....	1687	.....	.635
13 600	433.47	1140	1964	36.7	.655

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 222					
0	26.29	37	32	53.9	0.010
1000	56.29	66	55	54.6	.020
2000	86.29	101	87	53.8	.030
3000	116.29	138	115	54.5	.040
3500	131.29	158	128	55.3	.050
4000	146.29	188	154	55.0	.060
4500	161.29	211	183	53.5	.070
5000	176.29	240	217	52.5	.080
5500	191.29	270	253	51.6	.090
6000	206.29	299	285	51.2	.110
7000	236.29	361	393	47.9	.140
8000	266.29	421	485	46.5	.180
9000	296.29	488	585	45.5	.210
10 000	326.29	552	670	45.2	.250
11 000	356.29	627	769	44.9	.280
12 000	386.29	688	853	44.6	.320
13 000	416.29	772	930	45.4	.350
14 000	446.29	837	1014	45.2	.390
15 000	476.29	919	1115	45.2	.420
16 000	506.29	1003	1214	45.2	.460
17 000	536.29	1100	1332	45.2	.515
17 500	551.29	1159	1398	45.3	.540
17 820	560.89	.....	1443	.....	.560
17 100	539.29	1217	1547	44.0	.570
18 000	566.29	.....	1679	.....	.600
16 250	513.79	1338	2009	40.0	.620
BEAM 223					
0	26.09	45	44	50.8	0.005
2000	86.09	109	94	53.7	.030
3000	116.09	139	126	52.5	.000
4000	146.09	182	169	51.8	.060
5000	176.09	237	231	50.7	.090
6000	206.09	295	313	48.6	.110
7000	236.09	354	419	45.8	.150
8000	266.09	423	521	44.8	.180
9000	296.09	478	605	44.1	.210
10 000	326.09	542	703	43.5	.250
11 000	356.09	608	790	43.5	.290
12 000	386.09	671	884	43.1	.320
13 000	416.09	745	997	42.8	.360
14 000	446.09	805	1080	42.7	.390
15 000	476.09	877	1179	42.7	.430
16 000	506.09	928	1246	43.0	.460
17 000	536.09	1030	1352	43.2	.500
17 500	551.09	1071	1409	43.2	.520
18 000	566.09	1108	1465	43.1	.540
18 500	581.09	.....	1521	.....	.570
18 000	566.09	1177	1600	42.4	.575
.....	.....	.....	.....	.....	.600
19 000	596.09	1250	1716	42.1	.610
19 200	602.09	.....	1809	.....	.630
16 800	530.09	1336	2248	37.3	.660
BEAM 224					
0	25.88	37	31	54.7	0.010
2000	85.88	94	91	50.9	.040
3000	115.88	128	121	51.5	.050
4000	145.88	174	171	50.5	.070
5000	175.88	230	239	49.1	.090
6000	205.88	287	328	46.6	.120
7000	235.88	353	415	46.0	.150
8000	265.88	414	508	44.9	.190
9000	295.88	475	605	44.0	.220
10 000	325.88	544	692	44.0	.250
11 000	355.88	607	802	43.1	.290
12 000	385.88	677	903	42.8	.330
13 000	415.88	743	1005	42.5	.370
14 000	445.88	807	1106	42.2	.410
15 000	475.88	885	1197	42.5	.440
16 000	505.88	935	1292	42.5	.480
17 000	535.88	1045	1398	42.8	.530
18 000	565.88	1143	1579	42.0	.580
18 200	571.88	.....	1733	.....	.610
18 450	579.38	.....	1933	.....	.650
16 600	523.88	1310	2229	37.0	.670

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 237					
0	25.88	33	15	69.0	0.010
2000	85.88	106	65	61.9	.040
3000	115.88	144	85	63.0	.050
3500	130.88	180	91	66.4	.050
4000	145.88	209	109	65.7	.050
4500	160.88	241	133	64.4	.050
5000	175.88	275	164	62.6	.075
6000	205.88	338	241	58.4	.100
7000	235.88	402	318	55.8	.130
8000	265.88	470	398	54.2	.170
9000	295.88	518	499	50.9	.210
10 000	325.88	574	605	48.7	.240
11 000	355.88	646	656	49.6	.270
12 000	385.88	710	737	49.1	.310
13 000	415.88	781	814	49.0	.340
14 000	445.88	852	901	48.6	.370
15 000	475.88	925	988	48.3	.410
16 000	505.88	1003	1072	48.3	.440
17 000	535.88	1079	1185	47.7	.480
18 000	565.88	1159	1263	47.9	.510
19 000	595.88	1268	1335	48.7	.550
19 300	604.88	.....	1361	.....	.....
19 400	607.88	.....	1393	.....	.....
19 500	610.88	1383	1456	48.7	.620
19 650	615.38	.....	1474	.....	.640
17 600	553.88	1355	1400	49.2	.650
BEAM 238					
0	26.29	42	44	49.0	0.010
2000	86.29	107	94	53.2	.030
3000	116.29	143	125	53.4	.040
4000	146.29	184	169	52.1	.055
5000	176.29	228	232	49.6	.080
6000	206.29	279	303	47.9	.100
7000	236.29	332	383	46.4	.130
8000	266.29	408	474	46.3	.170
9000	296.29	461	557	45.3	.195
10 000	326.29	546	634	46.3	.230
11 000	356.29	612	725	45.8	.260
12 000	386.29	672	807	45.4	.290
13 000	416.29	734	882	45.4	.310
14 000	446.29	785	968	44.0	.340
15 000	476.29	842	1051	44.5	.380
16 000	506.29	899	1132	44.3	.410
17 000	536.29	972	1231	44.1	.440
18 000	566.29	1045	1344	43.8	.480
19 000	596.29	1187	1629	42.1	.550
19 150	600.79	.....	1679	.....	.560
17 500	551.29	1224	1947	38.6	.....
BEAM 239					
0	26.29	38	34	52.5	0.005
2000	86.29	103	85	54.9	.030
3000	116.29	135	113	54.5	.040
4000	146.29	173	144	54.6	.055
5000	176.29	217	191	53.2	.070
6000	206.29	270	255	51.5	.100
7000	236.29	337	340	49.8	.120
8000	266.29	399	434	47.9	.150
9000	296.29	451	521	46.4	.180
10 000	326.29	518	609	46.0	.210
11 000	356.29	589	691	46.0	.245
12 000	386.29	642	778	45.2	.280
13 000	416.29	702	860	44.9	.320
14 000	446.29	765	944	44.7	.350
15 000	476.29	833	1031	44.7	.380
16 000	506.29	899	1120	44.5	.420
17 000	536.29	990	1227	44.6	.460
18 000	566.29	1065	1328	44.5	.495
19 000	596.29	1148	1426	44.6	.540
19 500	611.29	.....	1485	.....	.590
19 630	615.19	.....	1576	.....	.590
19 920	623.89	.....	1774	.....	.625
18 000	566.29	.....	.....	.....	.640

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 165					
0	25.47	26	14	65.0	0.005
1000	55.47	72	36	65.8	.020
2000	85.47	104	56	65.0	.030
3000	115.47	134	87	60.6	.040
3500	130.47	155	106	59.4	.050
4000	145.47	183	156	54.0	.060
4500	160.47	258	325	44.3	.110
5000	175.47	307	485	38.7	.155
5500	190.47	351	643	35.3	.200
6000	205.47	400	843	32.2	.255
6500	220.47	447	1015	30.6	.305
6800	229.47	.....	1138	.....	.350
4900	172.47	384	1003	27.7	.355
BEAM 166					
0	25.26	23	17	57.5	0.010
1000	55.26	52	34	60.6	.020
2000	85.26	82	60	57.8	.030
3000	115.26	114	85	57.3	.040
3500	130.26	135	104	56.5	.050
4000	145.26	162	138	54.0	.060
4500	160.26	257	448	36.5	.130
5000	175.26	311	672	31.6	.185
5500	190.26	346	839	29.2	.240
6000	205.26	383	1027	27.2	.285
6500	220.26	418	1176	26.2	.325
5000	175.26	423	1634	20.6	.350
BEAM 167					
0	25.68	26	17	60.6	0.010
1000	55.68	63	36	63.6	.020
2000	85.68	92	62	59.7	.030
2500	100.68	108	77	58.4	.035
3000	115.68	127	98	58.0	.045
3500	130.68	148	116	56.1	.050
4000	145.68	193	238	44.7	.075
4500	160.68	253	432	37.0	.105
5000	175.68	336	740	31.2	.190
5500	190.68	384	882	30.3	.235
6000	205.68	416	1015	29.0	.275
6500	220.68	454	1147	28.4	.320
6600	223.68	.....	1164	.....	.345
5200	181.68	408	1063	27.8	.345

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 177					
0	25.47	24	19	56.0	0.010
1000	55.47	55	46	54.5	.020
2000	85.47	83	74	53.4	.030
3000	115.47	117	99	54.1	.040
3500	130.47	134	121	52.5	.050
4000	145.47	157	145	52.0	.060
4500	160.47	192	226	45.9	.080
5000	175.47	239	337	41.5	.100
6000	205.47	331	617	34.9	.180
7000	235.47	392	810	32.6	.240
8000	265.47	457	976	31.9	.310
8500	280.47	490	1063	31.5	.340
9000	295.47	527	1157	31.3	.370
9210	301.77	.....	1215	.....	.410
7600	253.47	500	1116	30.9	.410
BEAM 178					
0	25.47	19	22	46.4	0.010
1000	55.47	56	38	59.4	.020
2000	85.47	81	62	56.7	.035
3000	115.47	113	89	56.0	.050
3500	130.47	132	106	55.4	.055
4000	145.47	149	128	53.8	.060
4500	160.47	174	171	50.5	.075
5000	175.47	213	229	48.2	.090
6000	205.47	315	497	38.8	.160
7000	235.47	375	694	35.0	.220
8000	265.47	434	867	33.4	.280
9000	295.47	496	1046	32.2	.345
10 000	325.47	560	1248	31.0	.410
7700	256.47	507	817	38.3	.410
BEAM 179					
0	25.47	28	21	57.6	0.010
1000	55.47	53	43	55.1	.010
2000	85.47	79	67	54.2	.020
3000	115.47	107	96	52.7	.030
4000	145.47	138	123	52.9	.040
4500	160.47	157	144	52.2	.050
5000	175.47	184	178	50.8	.060
5500	190.47	227	253	47.3	.090
6000	205.47	276	369	42.8	.130
7000	235.47	356	588	37.7	.200
8000	265.47	413	776	34.8	.260
9000	295.47	498	949	34.4	.325
9840	320.67	.....	1070	.....	.390
8200	271.47	501	974	34.0	.400

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 189					
0	26.29	28	17	62.4	0.010
1000	56.29	58	36	61.6	.020
2000	86.29	87	58	60.1	.035
3000	116.29	118	82	59.0	.045
4000	146.29	150	113	57.1	.055
4500	161.29	171	137	55.6	.070
5000	176.29	189	166	53.2	.080
5500	191.29	217	214	50.3	.100
6000	206.29	248	282	46.7	.120
7000	236.29	328	460	41.7	.165
8000	266.29	411	597	40.8	.210
9000	296.29	462	726	38.9	.260
10 000	326.29	522	858	37.8	.305
11 000	356.29	592	988	37.5	.350
12 000	386.29	650	1125	36.6	.400
12 700	407.29	.....	1226	.....	.455
10 100	329.29	706	1853	27.6	.475
BEAM 190					
0	25.26	26	10	72.1	0.005
1000	55.26	62	21	74.7	.025
2000	85.26	94	43	68.6	.035
3000	115.26	126	74	63.0	.045
4000	145.26	160	106	60.2	.060
4500	160.26	181	128	58.6	.070
5000	175.26	207	164	55.7	.080
5500	190.26	234	209	52.8	.085
6000	205.26	279	292	48.8	.110
7000	235.26	357	477	42.8	.165
8000	265.26	420	656	39.0	.230
9000	295.26	489	814	37.5	.275
10 000	325.26	531	979	35.2	.320
11 000	355.26	590	1132	34.3	.370
12 000	385.26	651	1277	33.7	.415
12 500	400.26	682	1344	33.7	.445
12 560	402.06	.....	1374	.....	.475
9800	319.26	603	1150	34.4	.475
BEAM 191					
0	25.47	21	21	50.1	0.010
1000	55.47	43	44	49.6	.025
2000	85.47	72	68	51.4	.035
3000	115.47	107	92	53.8	.045
4000	145.47	145	116	55.6	.055
4500	160.47	165	135	55.0	.065
5000	175.47	190	159	54.5	.075
5500	190.47	218	191	53.4	.085
6000	205.47	261	244	51.7	.100
7000	235.47	346	421	45.1	.150
8000	265.47	411	588	41.1	.205
9000	295.47	469	735	39.0	.250
10 000	325.47	533	892	37.4	.300
11 000	355.47	588	1021	36.6	.345
11 780	378.87	.....	1176	.....	.400
10 100	328.47	673	1561	30.1	.420

Appendix II—Log Sheets for Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 201					
0	25.68	23	15	60.4	0.005
1000	55.68	50	32	61.0	.015
2000	85.68	79	55	58.9	.025
3000	115.68	112	77	59.4	.035
4000	145.68	142	101	58.5	.045
5000	175.68	186	152	55.0	.060
6000	205.68	236	250	48.6	.085
7000	235.68	311	405	43.4	.135
8000	265.68	372	542	40.7	.175
9000	295.68	429	682	38.6	.215
10 000	325.68	485	802	37.7	.255
11 000	355.68	548	916	37.4	.290
12 000	385.68	600	1045	36.5	.325
13 000	415.68	657	1164	36.1	.370
13 550	432.18	.....	1301	.....	.410
13 600	433.68	.....	1443	.....	.430
12 300	394.68	740	1680	30.6	.440
BEAM 202					
0	25.68	21	19	52.5	0.010
1000	55.68	48	39	55.4	.020
2000	85.68	79	65	54.9	.030
3000	115.68	109	92	54.2	.040
4000	145.68	144	130	52.5	.055
5000	175.68	190	190	50.0	.075
6000	205.68	249	291	46.1	.105
7000	235.68	316	429	42.4	.140
8000	265.68	379	566	40.1	.190
9000	295.68	437	687	38.9	.230
10 000	325.68	477	815	36.9	.270
11 000	355.68	549	957	36.5	.310
12 000	385.68	604	1084	35.8	.350
13 000	415.68	670	1215	35.6	.395
13 650	435.18	.....	1323	.....	.435
12 450	399.18	740	1634	31.2	.460
BEAM 203					
0	25.68	23	17	57.5	0.010
1000	55.68	55	44	55.5	.025
2000	85.68	77	67	53.5	.035
3000	115.68	106	91	53.8	.045
4000	145.68	136	118	53.5	.055
5000	175.68	174	173	50.2	.070
6000	205.68	233	255	47.8	.100
7000	235.68	296	391	43.1	.140
8000	265.68	363	532	40.5	.185
9000	295.68	418	662	38.7	.225
10 000	325.68	473	805	37.0	.265
11 000	355.68	527	920	36.4	.310
12 000	385.68	578	1043	35.7	.345
13 000	415.68	637	1166	35.3	.385
14 000	445.68	713	1361	34.4	.440
14 180	451.08	.....	1479	.....	.465
12 600	403.68	772	1882	29.1	.495

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 213					
0	26.09	23	15	60.4	0.005
1000	56.09	53	39	57.4	.015
2000	86.09	75	62	54.7	.020
3000	116.09	106	87	54.8	.030
4000	146.09	141	123	53.4	.045
5000	176.09	184	171	51.8	.060
6000	206.09	228	241	48.7	.080
7000	236.09	299	333	47.3	.115
8000	266.09	360	441	44.9	.150
9000	296.09	416	550	43.1	.185
10 000	326.09	471	665	41.4	.220
11 000	356.09	519	749	40.9	.255
12 000	386.09	572	856	40.1	.290
13 000	416.09	626	961	39.5	.325
14 000	446.09	670	1060	38.7	.365
15 000	476.09	723	1157	38.5	.400
16 000	506.09	782	1279	37.9	.435
16 550	522.59	.....	1321	.....	.470
14 800	470.09	777	1262	37.6	.480
BEAM 214					
0	25.68	23	17	57.5	0.010
1000	55.68	53	38	58.0	.020
2000	85.68	79	60	56.8	.030
3000	115.68	107	84	55.9	.040
4000	145.68	141	115	55.0	.055
5000	175.68	185	161	53.5	.075
6000	205.68	238	217	52.3	.100
7000	235.68	298	313	48.7	.130
8000	265.68	363	434	45.5	.165
9000	295.68	420	556	43.0	.210
10 000	325.68	469	683	41.3	.240
11 000	355.68	523	781	40.1	.275
12 000	385.68	570	885	39.2	.315
13 000	415.68	621	991	38.5	.355
14 000	445.68	682	1094	38.4	.390
15 000	475.68	748	1202	38.3	.430
16 000	505.68	803	1321	37.8	.465
16 800	529.68	.....	1494	.....	.525
14 600	463.68	877	1930	31.3	.530
BEAM 215					
0	26.29	21	15	58.1	0.010
1000	56.29	51	43	54.1	.020
2000	86.29	82	62	57.0	.030
3000	116.29	111	87	56.0	.040
4000	146.29	146	120	54.9	.050
5000	176.29	189	174	52.1	.070
6000	206.29	245	277	46.9	.100
7000	236.29	299	379	44.1	.130
8000	266.29	358	494	42.0	.160
9000	296.29	411	597	40.8	.195
10 000	326.29	461	708	39.5	.235
11 000	356.29	518	821	38.7	.275
12 000	386.29	567	932	37.8	.305
13 000	416.29	618	1038	37.3	.345
14 000	446.29	670	1144	36.9	.380
15 000	476.29	726	1250	36.7	.425
16 000	506.29	799	1368	36.9	.470
16 500	521.29	.....	1422	.....	.495
15 500	491.29	828	1540	34.9	.510

Appendix II—Log Sheets of Concrete Beams—Continued

BEAM 225

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
0	25.88	23	15	60.4	0.010
1000	55.88	55	31	64.1	.020
2000	85.88	84	55	60.4	.030
3000	115.88	116	77	60.0	.040
4000	145.88	145	108	57.3	.050
5000	175.88	185	147	55.8	.070
6000	205.88	229	205	52.7	.090
7000	235.88	296	289	50.6	.115
8000	265.88	355	379	48.3	.145
9000	295.88	414	479	46.3	.180
10 000	325.88	469	579	44.8	.210
11 000	355.88	522	682	43.4	.240
12 000	385.88	579	773	42.8	.275
13 000	415.88	625	868	41.8	.310
14 000	445.88	686	966	41.5	.345
15 000	475.88	732	1055	41.0	.375
16 000	505.88	788	1156	40.5	.410
17 000	535.88	839	1236	40.4	.440
18 000	565.88	913	1354	40.3	.485
18 250	573.38	.....	1503	.....	.510
17 250	543.38	1040	1926	35.1	.560

BEAM 226

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
0	26.09	19	12	60.7	0.005
1000	56.09	45	34	56.9	.015
2000	86.09	73	55	57.2	.025
3000	116.09	101	80	55.8	.035
4000	146.09	130	101	56.2	.045
5000	176.09	167	140	54.5	.055
6000	206.09	205	190	51.9	.075
7000	236.09	257	263	49.4	.095
8000	266.09	313	356	46.8	.125
9000	296.09	368	465	44.2	.155
10 000	326.09	421	574	42.3	.185
11 000	356.09	471	663	41.5	.215
12 000	386.09	522	754	40.9	.250
13 000	416.09	567	839	40.3	.285
14 000	446.09	617	932	39.9	.315
15 000	476.09	668	1021	39.5	.345
16 000	506.09	713	1109	39.1	.375
17 000	536.09	769	1205	38.9	.405
18 000	566.09	827	1321	38.5	.445
18 500	581.09	.....	1480	.....	.480
18 620	584.69	.....	1694	.....	.505
17 300	545.09	967	2075	31.8	.535

BEAM 227

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
0	26.29	19	17	52.5	0.005
1000	56.29	48	43	52.5	.015
2000	86.29	72	63	53.2	.025
3000	116.29	101	85	54.4	.035
4000	146.29	132	109	54.8	.045
5000	176.29	167	138	54.8	.055
6000	206.29	215	193	52.7	.075
7000	236.29	273	258	51.4	.095
8000	266.29	331	349	48.7	.125
9000	296.29	387	448	46.3	.155
10 000	326.29	437	550	44.3	.190
11 000	356.29	488	643	43.1	.220
12 000	386.29	543	732	42.6	.255
13 000	416.29	589	824	41.7	.285
14 000	446.29	634	911	41.0	.315
15 000	476.29	690	1007	40.7	.345
16 000	506.29	742	1103	40.2	.385
17 000	536.29	796	1197	39.9	.415
18 000	566.29	850	1308	39.4	.455
18 780	589.69	.....	1443	.....	.495
17 400	548.29	906	1513	37.5	.530

BEAM 243

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
0	26.29	26	17	60.6	0.010
1000	56.29	67	38	63.9	.025
2000	86.29	91	53	63.2	.035
3000	116.29	123	75	62.1	.045
4000	146.29	153	101	60.2	.060
5000	176.29	190	135	58.5	.080
6000	206.29	230	179	56.3	.100
7000	236.29	284	239	54.3	.120
8000	266.29	341	305	52.7	.140
9000	296.29	401	379	51.4	.170
10 000	326.29	446	472	48.6	.195
11 000	356.29	503	556	47.5	.225
12 000	386.29	547	643	45.9	.255
13 000	416.29	603	725	45.4	.285
14 000	446.29	647	805	44.5	.315
15 000	476.29	696	887	44.0	.345
16 000	506.29	746	966	43.6	.370
17 000	536.29	807	1039	43.7	.400
18 000	566.29	850	1115	43.3	.430
19 000	596.29	917	1215	43.0	.470
20 000	626.29	981	1340	42.3	.500
20 500	641.29	1038	1456	41.6	.535
21 000	656.29	1082	1562	40.9	.570
21 300	665.29	.....	1706	.....	.615
19 400	608.29	1182	2038	36.7	.630

BEAM 244

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
0	26.71	28	17	62.4	0.010
1000	56.71	52	32	62.0	.020
2000	86.71	79	53	59.7	.025
3000	116.71	105	72	59.3	.035
4000	146.71	129	91	58.6	.045
5000	176.71	163	115	58.6	.060
6000	206.71	196	156	55.6	.070
7000	236.71	242	209	53.6	.090
8000	266.71	293	275	51.6	.110
9000	296.71	339	354	48.9	.140
10 000	326.71	381	443	46.3	.170
11 000	356.71	427	532	44.5	.195
12 000	386.71	474	617	43.4	.225
13 000	416.71	519	697	42.7	.250
14 000	446.71	566	778	42.1	.280
15 000	476.71	608	856	41.5	.310
16 000	506.71	658	937	41.2	.340
17 000	536.71	703	1014	40.9	.365
18 000	566.71	750	1089	40.8	.395
19 000	596.71	808	1173	40.8	.430
20 000	626.71	860	1252	40.7	.460
21 000	656.71	927	1379	40.2	.510
21 280	665.11	.....	1405	.....	.530
19 400	608.71	890	1294	40.8	.540

BEAM 245

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
0	26.50	23	19	54.9	0.010
1000	56.50	48	43	52.5	.020
2000	86.50	74	63	54.0	.030
3000	116.50	101	85	54.4	.040
4000	146.50	127	108	54.0	.050
5000	176.50	162	140	53.7	.060
6000	206.50	197	181	52.1	.075
7000	236.50	243	244	49.9	.095
8000	266.50	293	304	49.1	.120
9000	296.50	340	388	46.7	.145
10 000	326.50	388	477	44.9	.170
11 000	356.50	431	564	43.3	.200
12 000	386.50	477	648	42.4	.230
13 000	416.50	525	728	41.9	.260
14 000	446.50	568	802	41.4	.285
15 000	476.50	615	879	41.2	.315
16 000	506.50	662	957	40.9	.345
17 000	536.50	704	1034	40.5	.370
18 000	566.50	753	1113	40.4	.400
19 000	596.50	809	1198	40.3	.430
20 000	626.50	870	1304	40.0	.470
21 000	656.50	938	1439	39.5	.510
22 000	686.50	1044	1720	37.8	.570
22 120	690.10	.....	1831	.....	.595
18 900	593.50	1108	2419	31.4	.620

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 169					
0	25.68	16	10	62.0	0.005
1000	55.68	35	32	52.5	.020
2000	85.68	59	55	51.6	.030
2500	100.68	70	68	50.7	.035
3000	115.68	86	85	50.2	.050
3500	130.68	115	133	46.5	.060
4000	145.68	153	212	42.0	.085
4500	160.68	202	421	32.4	.140
5000	175.68	265	586	31.1	.185
5500	190.68	307	766	28.6	.230
6000	205.68	349	942	27.1	.265
6500	220.68	389	1089	26.3	.315
6810	229.98	.....	1178	.....	.340
6050	207.18	385	1135	25.3	.350
BEAM 170					
0	25.68	19	14	57.1	0.010
1000	55.68	45	31	59.1	.025
2000	85.68	66	56	54.1	.035
2500	100.68	87	68	56.1	.045
3000	115.68	100	84	54.4	.055
3500	130.68	122	106	53.6	.060
4000	145.68	175	238	42.3	.095
4500	160.68	232	414	35.9	.145
5000	175.68	278	605	31.5	.190
5500	190.68	313	745	29.6	.230
6000	205.68	346	887	28.0	.270
6350	216.18	.....	1044	.....	.325
5230	182.58	350	979	26.4	.335
BEAM 180					
0	25.88	17	15	52.5	0.010
1000	55.88	33	43	43.3	.020
2000	85.88	59	67	47.0	.030
3000	115.88	88	97	47.6	.040
3500	130.88	109	126	46.3	.050
4000	145.88	135	159	45.9	.065
4500	160.88	163	222	42.4	.080
5000	175.88	195	306	39.1	.100
6000	205.88	270	499	35.2	.150
7000	235.88	336	691	32.7	.210
8000	265.88	396	870	31.3	.265
9000	295.88	462	1053	30.5	.320
9820	320.48	.....	1236	.....	.380
8000	265.88	575	2391	19.4	.470
BEAM 181					
0	25.88	16	12	57.8	0.010
1000	55.88	32	32	50.2	.020
2000	85.88	66	51	56.4	.030
3000	115.88	100	84	54.4	.050
3500	130.88	115	109	51.4	.060
4000	145.88	137	135	50.3	.070
4500	160.88	167	191	46.6	.080
5000	175.88	202	258	43.9	.105
5500	190.88	235	333	41.4	.130
6000	205.88	274	444	38.2	.160
7000	235.88	333	619	35.0	.210
8000	265.88	395	815	32.7	.270
9000	295.88	458	998	31.4	.325
10 000	325.88	508	1178	30.1	.380
10 780	349.28	.....	1303	.....	.425
8100	268.88	470	1133	29.3	.440
BEAM 182					
0	26.09	17	15	52.5	0.010
1000	56.09	51	51	50.1	.030
2000	86.09	70	70	50.0	.040
3000	116.09	94	99	48.6	.050
3500	131.09	120	123	49.4	.060
4000	146.09	148	168	46.8	.070
4500	161.09	179	222	44.6	.090
5000	176.09	211	289	42.2	.110
6000	206.09	294	528	35.8	.170
7000	236.09	356	708	33.5	.230
8000	266.09	414	891	31.7	.290
9000	296.09	478	1074	30.8	.350
10 000	326.09	533	1241	30.0	.405
8250	273.09	481	1132	29.8	.430
BEAM 192					
0	25.26	19	14	57.1	0.010
1000	55.26	38	38	49.9	.020
2000	85.26	62	62	50.1	.030
3000	115.26	93	87	51.7	.045
3500	130.26	114	104	52.3	.050
4000	145.26	136	130	51.2	.060
5000	175.26	183	197	48.2	.080
6000	205.26	240	311	43.5	.115
7000	235.26	315	475	39.8	.160
8000	265.26	383	629	37.8	.210
9000	295.26	449	774	36.7	.250
10 000	325.26	505	913	35.6	.300
11 000	355.26	568	1051	35.1	.345
12 000	385.26	627	1181	34.7	.390
12 360	396.06	.....	1280	.....	.425
10 900	352.26	627	1309	32.4	.430

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 193					
0	25.68	19	14	57.1	0.005
1000	55.68	45	41	52.5	.015
2000	85.68	79	65	54.9	.030
3000	115.68	111	92	54.7	.045
4000	145.68	146	125	53.8	.055
5000	175.68	201	190	51.3	.080
6000	205.68	273	308	47.0	.115
7000	235.68	337	456	42.5	.155
8000	265.68	396	593	40.1	.205
9000	295.68	462	727	38.9	.250
10 000	325.68	518	841	38.1	.290
11 000	355.68	585	962	37.8	.335
12 000	385.68	656	1089	37.6	.395
12 500	400.68	.....	1210	.....	.425
10 500	340.68	749	1786	29.5	.470
BEAM 194					
0	25.68	17	15	52.5	0.010
1000	55.68	37	31	54.7	.020
2000	85.68	61	50	54.8	.030
3000	115.68	90	77	54.0	.045
4000	145.68	122	103	54.3	.055
5000	175.68	164	178	48.0	.080
6000	205.68	213	250	46.0	.105
7000	235.68	272	412	39.8	.145
8000	265.68	338	605	35.9	.195
9000	295.68	382	754	33.6	.240
10 000	325.68	443	899	33.0	285
11 000	355.68	491	1034	32.2	.325
12 000	385.68	551	1173	32.0	.375
12 530	401.58	.....	1313	.....	.415
10 700	346.68	590	1708	25.7	.430
BEAM 204					
0	25.68	17	15	52.5	0.01
1000	55.68	37	32	53.9	.02
2000	85.68	64	55	53.8	.03
3000	115.68	91	82	52.5	.04
4000	145.68	127	121	51.3	.06
5000	175.68	175	191	47.9	.085
6000	205.68	236	297	44.2	.12
7000	235.68	294	421	41.1	.16
8000	265.68	345	540	39.0	.20
9000	295.68	398	667	37.4	.24
10 000	325.68	455	791	36.5	.28
11 000	355.68	500	887	36.1	.32
12 000	385.68	558	1014	35.5	.36
13 000	415.68	610	1138	34.9	.405
13 550	432.18	.....	1267	.....	.445
12 500	400.68	665	1485	30.9	.455

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 205					
0	26.29	19	19	49.9	0.010
1000	56.29	42	46	48.0	.020
2000	86.29	63	68	47.9	.030
3000	116.29	91	97	48.5	.045
4000	146.29	122	132	48.0	.060
5000	176.29	162	186	46.6	.080
6000	206.29	213	279	43.2	.110
7000	236.29	268	403	39.9	.140
8000	266.29	328	533	38.1	.180
9000	296.29	382	655	36.8	.220
10 000	326.29	429	781	35.5	.260
11 000	356.29	487	906	34.9	.300
12 000	386.29	534	1024	34.3	.340
13 000	416.29	583	1137	33.9	.380
14 000	446.29	653	1333	32.9	.440
14 730	468.19	.....	1684	.....	.540
13 730	438.19	722	1651	30.4	.555
BEAM 206					
0	25.68	19	21	47.5	0.010
1000	55.68	38	36	51.1	.020
2000	85.68	68	55	55.3	.030
3000	115.68	100	82	55.0	.050
4000	145.68	133	111	54.6	.065
5000	175.68	173	164	51.3	.085
6000	205.68	229	248	48.0	.120
7000	235.68	284	373	43.2	.160
8000	265.68	346	503	40.8	.200
9000	295.68	403	621	39.4	.240
10 000	325.68	450	744	37.7	.280
11 000	355.68	507	865	36.9	.320
12 000	385.68	551	983	35.9	.360
13 000	415.68	596	1096	35.2	.400
14 000	445.68	655	1258	34.2	.450
14 540	461.88	.....	1393	.....	.480
12 800	409.68	717	1756	29.0	.505
BEAM 216					
0	25.88	17	14	54.1	0.010
1000	55.88	45	31	59.1	.020
2000	85.88	68	51	57.1	.030
3000	115.88	92	70	56.8	.040
4000	145.88	127	106	54.4	.050
5000	175.88	168	154	52.2	.070
6000	205.88	214	214	50.1	.100
7000	235.88	274	294	48.3	.130
8000	265.88	333	393	45.9	.170
9000	295.88	386	496	43.8	.200
10 000	325.88	443	603	42.4	.240
11 000	355.88	498	704	41.4	.270
12 000	385.88	547	802	40.6	.310
13 000	415.88	594	872	40.5	.345
14 000	445.88	660	978	40.3	.380
15 000	475.88	708	1077	39.7	.415
16 000	505.88	808	1292	38.5	.480
14 500	460.88	853	1739	32.9	.520

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 217					
0	26.09	19	14	57.1	0.005
1000	56.09	43	29	59.5	.02
2000	86.09	64	50	56.0	.03
3000	116.09	92	74	55.5	.04
4000	146.09	124	101	55.2	.05
5000	176.09	160	147	52.2	.07
6000	206.09	205	203	50.3	.09
7000	236.09	252	274	47.9	.125
8000	266.09	300	342	46.7	.16
9000	296.09	350	439	44.4	.19
10 000	326.09	404	542	42.7	.23
11 000	356.09	445	633	41.3	.26
12 000	386.09	493	733	40.2	.295
13 000	416.09	544	829	39.6	.33
14 000	446.09	592	930	38.9	.365
15 000	476.09	643	1041	38.2	.405
16 000	506.09	703	1171	37.5	.445
16 350	516.59	.....	1224	.....	.47
15 300	485.09	777	1735	30.9	.515
BEAM 218					
0	26.29	16	15	50.9	0.005
1000	56.29	38	36	51.1	.020
2000	86.29	56	55	50.2	.030
3000	116.29	82	82	50.1	.045
4000	146.29	112	116	49.2	.060
5000	176.29	155	185	45.6	.080
6000	206.29	197	255	43.5	.100
7000	236.29	240	342	42.1	.130
8000	266.29	304	415	42.3	.160
9000	296.29	359	525	40.6	.200
10 000	326.29	406	629	39.2	.230
11 000	356.29	456	733	38.4	.270
12 000	386.29	503	836	37.6	.305
13 000	416.29	555	937	37.2	.340
14 000	446.29	604	1015	37.3	.375
15 000	476.29	653	1130	36.6	.410
16 000	506.29	712	1251	36.3	.450
16 300	515.29	.....	1337	.....	.480
14 900	473.29	760	1802	30.2	.510
BEAM 231					
0	26.29	21	15	58.1	0.005
1000	56.29	43	34	55.8	.015
2000	86.29	66	51	56.3	.025
3000	116.29	92	67	57.8	.035
4000	146.29	124	91	57.6	.045
5000	176.29	158	121	56.6	.060
6000	206.29	194	171	53.2	.080
7000	236.29	236	236	50.0	.100
8000	266.29	283	323	46.7	.130
9000	296.29	341	415	45.1	.160
10 000	326.29	387	504	43.4	.190
11 000	356.29	434	595	42.2	.220
12 000	386.29	483	696	41.0	.250
13 000	416.29	529	786	40.2	.280
14 000	446.29	567	862	39.7	.310
15 000	476.29	603	942	39.0	.340
16 000	506.29	650	1034	38.6	.370
17 000	536.29	700	1120	38.5	.405
18 000	566.29	746	1226	37.9	.440
18 980	595.69	.....	1309	.....	.475
16 600	524.29	848	1896	30.9	.510

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 232					
0	26.29	19	14	57.1	0.010
1000	56.29	42	36	53.8	.020
2000	86.29	61	53	53.4	.030
3000	116.29	93	72	56.4	.040
4000	146.29	119	97	55.1	.050
5000	176.29	149	133	52.9	.065
6000	206.29	197	183	51.8	.085
7000	236.29	238	248	49.0	.110
8000	266.29	282	333	45.8	.135
9000	296.29	330	426	43.6	.165
10 000	326.29	376	503	42.8	.195
11 000	356.29	425	605	41.2	.225
12 000	386.29	465	689	40.3	.250
13 000	416.29	506	785	39.1	.280
14 000	446.29	546	872	38.5	.310
15 000	476.29	558	961	38.0	.340
16 000	506.29	631	1048	37.6	.370
17 000	536.29	681	1140	37.4	.405
18 000	566.29	725	1239	36.9	.440
19 000	596.29	798	1313	37.8	.480
19 570	613.39	.....	1436	.....	.....
16 700	527.29	837	1586	34.5	.570
BEAM 233					
0	26.29	13	14	48.8	0.005
1000	56.29	35	27	56.5	.015
2000	86.29	58	46	55.9	.030
3000	116.29	84	65	56.5	.040
4000	146.29	118	91	56.6	.050
5000	176.29	162	135	54.5	.070
6000	206.29	199	195	50.5	.085
7000	236.29	234	251	48.3	.110
8000	266.29	278	320	46.5	.135
9000	296.29	331	405	45.0	.160
10 000	326.29	382	496	43.5	.195
11 000	356.29	430	585	42.4	.220
12 000	386.29	469	665	41.3	.250
13 000	416.29	522	757	40.8	.285
14 000	446.29	562	834	40.2	.315
15 000	476.29	609	916	39.9	.345
16 000	506.29	659	997	39.8	.370
17 000	536.29	704	1072	39.6	.405
18 000	566.29	759	1168	39.4	.440
19 000	596.29	827	1299	38.9	.480
19 480	610.69	.....	1474	.....	.520
17 760	559.09	1011	2342	30.2	.600
BEAM 240					
0	26.29	15	12	56.2	0.010
1000	56.29	39	29	57.6	.020
2000	86.29	58	51	53.4	.030
3000	116.29	85	70	54.8	.040
4000	146.29	113	87	56.5	.050
5000	176.29	145	116	55.6	.060
6000	206.29	183	152	54.6	.085
7000	236.29	232	214	52.1	.100
8000	266.29	281	282	49.9	.125
9000	296.29	328	354	48.1	.150
10 000	326.29	378	436	46.4	.175
11 000	356.29	423	525	44.6	.210
12 000	386.29	468	602	43.8	.235
13 000	416.29	515	680	43.1	.260
14 000	446.29	558	756	42.5	.290
15 000	476.29	607	834	42.1	.320
16 000	506.29	652	913	41.7	.350
17 000	536.29	700	1007	41.0	.380
18 000	566.29	747	1065	41.2	.405
19 000	596.29	801	1132	41.4	.435
20 000	626.29	856	1219	41.2	.465
21 000	656.29	916	1338	40.6	.500
21 620	674.89	.....	1438	.....	.550
18 900	593.29	923	1328	41.0	.560

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 242					
0	26.29	15	12	56.2	0.010
1000	56.29	45	29	60.6	.020
2000	86.29	71	46	60.6	.030
3000	116.29	95	62	60.5	.035
4000	146.29	125	84	59.9	.075
5000	176.29	159	121	56.8	.090
6000	206.29	202	173	53.8	.110
7000	236.29	238	229	51.0	.130
8000	266.29	282	291	49.2	.150
9000	296.29	323	362	47.2	.175
10 000	326.29	374	439	46.0	.200
11 000	356.29	425	518	45.1	.230
12 000	386.29	480	590	44.8	.260
13 000	416.29	527	644	45.0	.280
14 000	446.29	572	738	43.6	.310
15 000	476.29	628	815	43.5	.340
16 000	506.29	679	891	43.2	.370
17 000	536.29	720	959	42.9	.400
18 000	566.29	770	1041	42.5	.425
19 000	596.29	812	1126	41.9	.455
20 000	626.29	855	1200	41.6	.485
21 000	656.29	913	1284	41.6	.515
22 000	686.29	1005	1494	40.2	.570
22 480	700.69	.....	1619	.....	.600
19 650	615.79	1071	2132	33.4	.610
BEAM 171					
0	25.26	21	14	59.7	.010
1000	55.26	47	34	58.1	.020
2000	85.26	73	53	58.0	.030
3000	115.26	96	75	56.0	.040
4000	145.26	124	97	56.1	.050
5000	175.26	166	179	48.2	.170
6000	205.26	320	812	28.2	.200
7000	235.26	383	1144	25.0	.280
7300	244.26	.....	1347	.....	.345
5350	185.76	382	1846	17.1	.350
BEAM 172					
0	25.26	21	14	59.7	0.010
1000	55.26	45	31	59.1	.020
2000	85.26	69	55	55.7	.030
3000	115.26	100	77	56.5	.040
4000	145.26	123	111	52.5	.055
5000	175.26	227	354	39.1	.110
6000	205.26	339	761	30.8	.220
7000	235.26	415	1055	28.3	.305
5100	178.26	433	2072	17.3	.405

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 173					
0	25.68	23	22	51.4	0.010
1000	55.68	48	39	55.4	.020
2000	85.68	79	62	56.0	.030
3000	115.68	107	96	52.7	.040
4000	145.68	164	169	49.2	.060
5000	175.68	270	503	34.9	.135
6000	205.68	353	827	30.2	.230
7000	235.68	424	1067	28.4	.320
7200	241.68	.....	1104	.....	.345
5200	181.68	374	949	28.3	.350
BEAM 183					
0	25.68	13	14	54.1	0.010
1000	55.68	42	36	53.8	.020
2000	85.68	70	62	52.9	.030
3000	115.68	101	92	52.2	.050
4000	145.68	139	144	49.1	.065
5000	175.68	191	250	43.3	.090
6000	205.68	269	468	36.5	.130
7000	235.68	343	728	32.0	.200
8000	265.68	411	940	30.5	.255
9000	295.68	473	1118	29.7	.305
10 000	325.68	526	1313	28.6	.360
10 750	348.18	.....	1573	.....	.430
8800	289.68	571	2085	21.5	.430
BEAM 184					
0	25.68	21	17	55.1	0.010
1000	55.68	47	41	53.6	.020
2000	85.68	74	62	54.3	.030
3000	115.68	104	92	53.0	.045
4000	145.68	136	125	52.1	.060
5000	175.68	183	193	48.6	.075
6000	205.68	263	379	41.0	.115
7000	235.68	353	639	35.6	.185
8000	265.68	427	870	32.9	.245
9000	295.68	493	1065	31.6	.305
10 000	325.68	(567)	1280	(30.7)	.375
7700	256.68	538	1885	22.2	.385

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 185					
0	25.88	21	15	58.1	0.010
1000	55.88	47	34	58.1	.020
2000	85.88	71	51	58.2	.030
3000	115.88	100	79	55.9	.045
4000	145.88	127	108	54.0	.055
5000	175.88	165	150	52.3	.075
6000	205.88	223	270	45.2	.100
7000	235.88	303	494	38.0	.170
8000	265.88	355	670	34.7	.225
9000	295.88	410	858	32.4	.285
10 000	325.88	464	1014	31.4	.345
10 670	345.98	.....	1115	.....	.....
7650	355.38	405	904	31.0	.405
BEAM 195					
0	25.06	21	19	52.5	0.010
1000	55.06	43	34	55.8	.020
2000	85.06	73	53	58.0	.030
3000	115.06	100	72	58.0	.040
4000	145.06	129	94	57.9	.050
5000	175.06	161	121	57.1	.065
6000	205.06	205	183	52.9	.085
7000	235.06	287	345	45.4	.130
8000	265.06	352	511	40.8	.180
9000	295.06	413	658	38.5	.220
10 000	325.06	457	783	36.9	.270
11 000	355.06	508	901	36.1	.310
12 000	385.06	563	1022	35.5	.355
13 000	415.06	613	1135	35.1	.400
13 670	435.16	.....	1217	.....	.445
11 100	358.06	562	1106	33.7	.470
BEAM 196					
0	25.88	23	15	60.4	0.010
1000	55.88	47	39	54.8	.020
2000	85.88	74	58	55.9	.030
3000	115.88	100	82	55.0	.040
4000	145.88	127	104	54.9	.050
5000	175.88	160	138	53.7	.065
6000	205.88	202	214	48.5	.085
7000	235.88	270	347	43.7	.120
8000	265.88	339	515	39.7	.170
9000	295.88	393	668	37.0	.210
10 000	325.88	444	812	35.3	.260
11 000	355.88	511	950	35.0	.300
12 000	385.88	567	1085	34.3	.340
13 000	415.88	612	1214	33.5	.390
10 300	340.88	657	2074	24.0	.440

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 197					
0	25.88	23	17	57.5	0.010
1000	55.88	50	36	58.3	.020
2000	85.88	79	55	58.9	.030
3000	115.88	106	77	58.0	.040
4000	145.88	133	108	55.2	.050
5000	175.88	172	147	53.9	.065
6000	205.88	217	222	49.4	.085
7000	235.88	283	364	43.8	.125
8000	265.88	339	504	40.2	.165
9000	295.88	399	648	38.1	.210
10 000	325.88	452	785	36.5	.255
11 000	355.88	500	918	35.3	.295
12 000	385.88	560	1060	34.6	.345
13 000	415.88	605	1178	33.9	.385
13 100	418.88	.....	.....	.....	.415
10 650	345.38	565	1135	33.2	.435
BEAM 207					
0	25.88	21	15	58.1	0.005
1000	55.88	47	32	59.5	.015
2000	85.88	77	58	57.0	.025
3000	115.88	107	85	55.6	.040
4000	145.88	136	115	54.1	.050
5000	175.88	174	161	51.9	.065
6000	205.88	225	239	48.5	.090
7000	235.88	275	338	44.8	.125
8000	265.88	345	482	41.7	.165
9000	295.88	401	614	39.5	.205
10 000	325.88	452	732	38.2	.245
11 000	355.88	507	856	37.2	.285
12 000	385.88	568	981	36.7	.325
13 000	415.88	618	1111	35.8	.360
14 000	445.88	680	1253	35.2	.410
14 500	460.88	.....	1472	.....	.430
12 400	397.88	746	1986	27.3	.480
BEAM 208					
0	26.09	21	17	55.1	0.010
1000	56.09	50	36	58.3	.020
2000	86.09	73	56	56.7	.030
3000	116.09	106	77	58.0	.040
4000	146.09	137	106	56.4	.050
5000	176.09	172	142	54.7	.070
6000	206.09	214	200	51.7	.090
7000	236.09	273	301	47.5	.120
8000	266.09	337	421	44.5	.160
9000	296.09	405	552	42.3	.200
10 000	326.09	462	680	40.5	.240
11 000	356.09	519	807	39.2	.280
12 000	386.09	576	928	38.3	.320
13 000	416.09	628	1053	37.4	.360
14 000	446.09	691	1173	37.2	.400
15 000	476.09	745	1291	36.6	.440
15 770	499.19	.....	1518	.....	.500
12 900	413.09	836	2202	27.5	.530

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 209					
0	26.29	17	15	52.5	0.010
1000	56.29	45	38	54.3	.020
2000	86.29	69	60	53.7	.030
3000	116.29	100	82	55.0	.040
4000	146.29	133	108	55.2	.055
5000	176.29	165	149	52.5	.070
6000	206.29	204	219	48.2	.090
7000	236.29	263	315	45.5	.115
8000	266.29	324	453	41.7	.155
9000	296.29	374	602	38.3	.205
10 000	326.29	431	723	37.3	.245
11 000	356.29	474	824	36.5	.280
12 000	386.29	532	949	35.9	.315
13 000	416.29	578	1065	35.2	.355
14 000	446.29	635	1185	34.9	.400
15 000	476.29	685	1318	34.2	.435
15 380	487.69	.....	1379	.....	.465
12 500	401.29	614	1243	33.1	.485
BEAM 219					
0	26.29	23	21	52.5	0.010
1000	56.29	42	38	52.5	.020
2000	86.29	68	58	54.1	.030
3000	116.29	92	75	55.2	.040
4000	146.29	119	97	55.1	.050
5000	176.29	148	121	55.1	.060
6000	206.29	195	190	50.7	.080
7000	236.29	251	292	46.2	.110
8000	266.29	311	402	43.6	.145
9000	296.29	368	526	41.1	.175
10 000	326.29	420	660	38.9	.215
11 000	356.29	470	750	38.5	.250
12 000	386.29	520	860	37.7	.285
13 000	416.29	568	966	37.0	.325
14 000	446.29	618	1072	36.5	.350
15 000	476.29	669	1142	36.9	.390
16 000	506.29	727	1338	35.2	.430
17 000	536.29	789	1496	34.5	.480
17 700	557.29	.....	1639	.....	.530
15 350	486.79	810	1713	32.1	.560
BEAM 220					
0	26.09	23	15	60.4	0.010
1000	56.09	45	43	51.4	.020
2000	86.09	69	58	54.5	.030
3000	116.09	98	79	55.3	.040
4000	146.09	122	104	54.0	.055
5000	176.09	166	147	53.0	.065
6000	206.09	214	210	50.5	.085
7000	236.09	259	287	47.5	.115
8000	266.09	315	379	45.4	.145
9000	296.09	380	487	43.9	.180
10 000	326.09	425	603	41.4	.220
11 000	356.09	484	709	40.6	.255
12 000	386.09	523	812	39.2	.290
13 000	416.09	570	913	38.4	.325
14 000	446.09	620	1019	37.8	.365
15 000	476.09	663	1116	37.3	.400
16 000	506.09	715	1248	36.4	.435
16 600	524.09	.....	1749	.....	.535
14 900	473.09	887	2632	25.2	.600

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 221					
0	26.29	19	21	47.5	0.005
1000	56.29	38	41	48.1	.015
2000	86.29	64	60	51.7	.020
3000	116.29	91	85	51.6	.030
4000	146.29	117	111	51.4	.040
5000	176.29	147	137	51.8	.060
6000	206.29	179	185	49.2	.080
7000	236.29	234	270	46.5	.100
8000	266.29	286	368	43.7	.130
9000	296.29	332	475	41.2	.160
10 000	326.29	387	598	39.3	.195
11 000	356.29	442	708	38.5	.230
12 000	386.29	489	815	37.5	.260
13 000	416.29	536	932	36.5	.300
14 000	446.29	589	1036	36.3	.335
15 000	476.29	639	1145	35.8	.370
16 000	506.29	688	1241	35.6	.405
17 000	536.29	746	1350	35.6	.440
17 660	556.09	.....	1438	.....	.470
15 300	485.29	805	2044	28.3	.520
BEAM 228					
0	26.29	19	22	46.4	0.005
1000	56.29	43	43	50.2	.020
2000	86.29	70	63	52.5	.030
3000	116.29	99	94	51.2	.040
4000	146.29	128	121	51.5	.050
5000	176.29	160	144	52.7	.060
6000	206.29	195	181	51.8	.075
7000	236.29	246	246	50.0	.100
8000	266.29	298	323	48.0	.125
9000	296.29	351	409	46.2	.150
10 000	326.29	402	492	44.9	.180
11 000	356.29	442	586	43.0	.210
12 000	386.29	502	685	42.3	.245
13 000	416.29	546	771	41.4	.275
14 000	446.29	590	850	41.0	.305
15 000	476.29	648	947	40.6	.335
16 000	506.29	693	1024	40.4	.365
17 000	536.29	741	1121	39.8	.400
18 000	566.29	800	1214	39.7	.435
19 000	596.29	846	1320	39.1	.470
20 000	626.29	908	1436	38.7	.505
20 650	645.79	.....	1644	.....	.560
17 850	561.79	1007	2178	31.6	.585
BEAM 229					
0	26.29	17	15	52.5	0.010
1000	56.29	47	31	60.2	.020
2000	86.29	76	53	59.1	.030
3000	116.29	105	74	58.6	.040
4000	146.29	133	103	56.3	.055
5000	176.29	172	144	54.4	.065
6000	206.29	211	197	51.8	.085
7000	236.29	258	262	49.6	.105
8000	266.29	310	349	47.0	.135
9000	296.29	361	436	45.3	.165
10 000	326.29	407	513	44.2	.190
11 000	356.29	458	607	43.0	.220
12 000	386.29	508	694	42.3	.250
13 000	416.29	551	778	41.5	.280
14 000	446.29	593	862	40.7	.310
15 000	476.29	644	952	40.3	.345
16 000	506.29	689	1036	39.9	.375
17 000	536.29	736	1123	39.6	.405
18 000	566.29	791	1207	39.6	.435
19 000	596.29	836	1294	39.3	.465
20 000	626.29	893	1388	39.2	.500
20 750	648.79	.....	1585	.....	.545
17 400	548.29	988	2526	28.1	.595

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 230					
0	27.01	28	15	57.2	0.005
1000	57.01	46	38	54.7	.015
2000	87.01	70	59	54.2	.025
3000	117.01	96	87	52.5	.035
4000	147.01	129	112	53.5	.045
5000	177.01	160	145	52.3	.055
6000	207.01	196	192	50.4	.080
7000	237.01	238	260	47.8	.100
8000	267.01	280	340	45.4	.120
9000	297.01	330	427	43.5	.160
10 000	327.01	375	525	41.6	.180
11 000	357.01	417	611	40.5	.215
12 000	387.01	465	707	39.6	.240
13 000	417.01	508	795	38.9	.270
14 000	447.01	556	880	38.7	.305
15 000	477.01	600	975	38.1	.335
16 000	507.01	640	1053	37.8	.365
17 000	537.01	684	1150	37.3	.395
18 000	567.01	733	1233	37.2	.425
19 000	597.01	781	1331	36.9	.460
20 000	627.01	830	1440	36.5	.480
21 000	657.01	884	1580	35.8	.535
17 400	549.01	792	1397	36.1	.545
BEAM 234					
0	26.29	21	17	55.1	0.010
1000	56.29	42	41	50.7	.020
2000	86.29	67	68	49.5	.030
3000	116.29	94	97	49.1	.040
4000	146.29	124	132	48.4	.050
5000	176.29	162	169	48.9	.070
6000	206.29	207	227	47.7	.090
7000	236.29	253	291	46.5	.110
8000	266.29	308	366	45.7	.140
9000	296.29	352	434	44.8	.165
10 000	326.29	402	518	43.7	.195
11 000	356.29	456	602	43.1	.225
12 000	386.29	508	691	42.1	.260
13 000	416.29	554	785	41.4	.285
14 000	446.29	612	880	41.0	.320
15 000	476.29	664	966	40.8	.345
16 000	506.29	718	1058	40.4	.380
17 000	536.29	767	1142	40.2	.410
18 000	566.29	817	1229	39.9	.440
19 000	596.29	885	1337	39.8	.470
20 000	626.29	932	1424	39.6	.510
21 000	656.29	1015	1607	38.7	.550
18 950	594.79	1197	2562	31.8	.650
BEAM 235					
0	26.29	19	15	49.9	0.015
1000	56.29	42	30	51.9	.025
2000	86.29	79	56	58.4	.035
3000	116.29	116	77	60.0	.045
4000	146.29	148	108	57.8	.055
5000	176.29	187	140	57.2	.070
6000	206.29	230	183	55.8	.090
7000	236.29	281	234	54.5	.110
8000	266.29	329	297	52.5	.140
9000	296.29	380	385	49.7	.170
10 000	326.29	428	470	47.7	.195
11 000	356.29	486	559	46.5	.220
12 000	386.29	532	636	45.6	.250
13 000	416.29	578	720	44.5	.280
14 000	446.29	634	807	44.0	.310
15 000	476.29	679	891	43.2	.340
16 000	506.29	724	978	42.5	.370
17 000	536.29	771	1055	42.2	.400
18 000	566.29	824	1144	41.9	.430
19 000	596.29	884	1229	41.8	.465
20 000	626.29	930	1297	41.8	.495
21 000	656.29	980	1390	41.4	.525
22 000	686.29	1042	1489	41.2	.570
22 100	689.29	.....	1648	.....	.620
18 850	591.79	998	1494	40.1	.625

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 236					
0	26.29	19	21	47.5	0.010
1000	56.29	47	38	55.4	.020
2000	86.29	75	56	57.1	.025
3000	116.29	100	82	55.0	.040
4000	146.29	132	113	53.9	.055
5000	176.29	168	157	51.7	.070
6000	206.29	206	214	49.0	.090
7000	236.29	255	263	49.2	.115
8000	266.29	312	343	47.7	.135
9000	296.29	355	419	45.8	.165
10 000	326.29	409	489	45.5	.185
11 000	356.29	458	566	44.7	.215
12 000	386.29	504	648	43.7	.245
13 000	416.29	559	738	43.1	.275
14 000	446.29	604	810	42.7	.305
15 000	476.29	655	887	42.5	.335
16 000	506.29	704	960	42.2	.365
17 000	536.29	757	1044	42.0	.395
18 000	566.29	802	1125	41.6	.425
19 000	596.29	852	1209	41.3	.455
20 000	626.29	901	1291	41.1	.485
21 000	656.29	970	1458	40.0	.525
22 000	686.29	.....	1790	.....	.605
18 400	578.29	1093	2453	30.8	.625
BEAM 256					
0	25.47	30	29	50.8	.01
1000	55.47	60	63	48.8	.02
2000	85.47	104	94	52.5	.04
2500	100.47	119	113	51.2	.05
3000	115.47	150	147	50.5	.06
3250	122.97	208	301	40.9	.095
3500	130.47	271	463	36.9	.13
4000	145.47	326	653	33.3	.18
4500	160.47	380	832	31.3	.23
5000	175.47	444	990	30.9	.275
5500	190.47	496	1121	30.7	.32
6000	205.47	535	1230	30.1	.37
6350	215.97	.....	(1321)	.....	.405
4500	160.47	548	2007	21.4	.44
BEAM 257					
0	25.47	37	17	68.3	0.01
1000	55.47	78	36	68.3	.02
2000	85.47	122	63	66.0	.03
2500	100.47	144	82	63.8	.04
3000	115.47	174	108	61.7	.05
3250	122.97	207	167	55.3	.06
3500	130.47	251	272	48.0	.085
4000	145.47	337	532	38.8	.15
4500	160.47	388	573	36.6	.21
5000	175.47	437	853	33.8	.26
5500	190.47	475	973	32.8	.305
5800	199.47	.....	(1031)	.....	.33
5900	202.47	.....	(1111)	.....	.35
4550	161.97	534	1614	24.9	.37

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 261					
0	26.09	27	24	52.5	0.010
1000	56.09	50	48	51.0	.020
2000	86.09	85	77	52.5	.035
3000	116.09	123	109	52.9	.045
3500	131.09	149	137	52.2	.055
4000	146.09	182	185	49.6	.075
4500	161.09	232	306	43.1	.105
5000	176.09	289	439	39.7	.155
6000	206.09	351	646	35.2	.215
7000	236.09	432	824	34.4	.275
8000	266.09	509	1009	33.5	.335
9000	296.09	586	1169	33.4	.395
9420	308.69	.....	(1233)	.....	.425
BEAM 262					
0	25.88	25	27	47.7	0.010
1000	55.88	51	58	47.0	.020
2000	85.88	80	87	48.0	.035
3000	115.88	118	121	49.4	.050
3500	130.88	143	150	48.7	060
4000	145.88	184	225	45.1	.075
4500	160.88	257	446	36.6	.120
5000	175.88	309	567	35.3	.150
6000	205.88	377	774	32.7	.220
7000	235.88	452	964	31.9	.270
8000	265.88	533	1150	31.7	.330
8500	280.88	567	1268	30.9	.365
9000	295.88	605	1376	30.5	.395
9320	305.48	.....	(1451)	.....	.420
BEAM 263					
0	26.09	25	27	47.7	0.010
1000	56.09	52	59	46.6	.025
2000	86.09	82	89	47.8	.035
3000	116.09	114	121	48.5	.045
3500	131.09	139	136	50.5	.055
4000	146.09	164	183	47.3	.065
4500	161.09	236	368	37.8	.105
5000	176.09	288	519	35.7	.145
6000	206.09	364	728	33.3	.210
7000	236.09	439	919	32.3	.275
8000	266.09	511	1162	30.5	.340
8470	280.19	.....	(1314)	.....	.385
7500	251.09	573	1870	23.5	.415

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 273					
0	26.09	28	27	50.7	0.010
1000	56.09	60	58	50.8	.020
2000	86.09	92	87	51.4	.040
3000	115.09	129	116	52.7	.050
3500	131.09	148	136	52.1	.060
4000	146.09	175	160	52.2	.070
4500	161.09	205	208	49.6	.080
5000	176.09	254	282	47.4	.110
6000	206.09	335	471	41.6	.155
7000	236.09	407	641	38.9	.210
8000	266.09	473	791	37.4	.255
9000	296.09	543	953	36.3	.305
10 000	326.09	612	1100	35.7	.350
11 000	356.09	693	1251	35.7	.405
11 300	365.09	.....	(1381)	.....	.435
10 300	335.09	739	1849	28.6	.450
BEAM 274					
0	26.09	28	25	52.5	0.010
1000	56.09	56	47	54.4	.015
2000	86.09	86	80	51.9	.030
3000	116.09	122	110	52.5	.040
3500	131.09	139	129	51.9	.050
4000	146.09	161	148	52.2	.060
4500	161.09	193	191	50.3	.075
5000	176.09	230	247	48.2	.080
6000	206.09	318	444	41.7	.130
7000	236.09	383	615	38.4	.185
8000	266.09	447	762	37.0	.210
9000	296.09	524	921	36.3	.255
10 000	326.09	593	1087	35.3	.305
10 800	350.09	.....	(1269)	.....	.350
10 100	329.09	714	1681	29.8	.395
BEAM 275					
0	26.29	27	22	55.5	0.010
1000	56.29	57	49	53.9	.020
2000	86.29	91	77	54.3	.040
3000	116.29	128	101	56.0	.050
3500	131.29	148	125	54.2	.060
4000	146.29	176	148	54.4	.070
4500	161.29	201	181	52.6	.080
5000	176.29	244	237	50.7	.100
6000	206.29	335	460	42.1	.155
7000	236.29	402	613	39.6	.205
8000	266.29	454	764	37.3	.250
9000	296.29	529	894	37.2	.290
10 000	326.29	604	1063	36.2	.340
11 000	356.29	682	1214	36.0	.370
11 500	371.29	.....	(1306)	.....	.400
10 400	338.29	734	1507	32.8	.410

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 285					
0	25.88	27	20	57.8	0.010
1000	55.88	59	47	55.8	.025
2000	85.88	93	68	57.8	.035
3000	115.88	127	95	57.2	.045
3500	130.88	149	114	56.7	.055
4000	145.88	170	136	55.6	.065
4500	160.88	198	177	52.8	.075
5000	175.88	232	244	48.7	.085
6000	205.88	308	384	44.5	.125
7000	235.88	385	547	41.3	.175
8000	265.88	455	685	39.9	.215
9000	295.88	518	815	38.8	.240
10 000	325.88	585	965	37.7	.285
11 000	355.88	657	1078	37.9	.335
12 000	385.88	739	1242	37.3	.375
13 000	415.88	.....	(1394)	.....	.430
13 000	415.88	803	1400	36.5	.445
12 500	400.88	.....	.....	.....	.475
BEAM 286					
0	26.09	26	18	59.3	0.010
1000	56.09	60	40	60.0	.020
2000	86.09	92	58	57.5	.040
3000	116.09	127	90	58.5	.050
3500	131.09	148	103	58.9	.060
4000	146.09	171	122	58.3	.065
4500	161.09	190	146	56.5	.075
5000	176.09	228	192	54.3	.090
6000	206.09	296	315	48.4	.130
7000	236.09	372	474	44.0	.175
8000	266.09	433	623	41.0	.225
9000	296.09	489	753	39.4	.265
10 000	326.09	552	880	38.5	.305
11 000	356.09	613	994	38.2	.350
12 000	386.09	688	1114	38.2	.400
13 500	401.09	732	1196	38.0	.425
13 000	416.09	764	1256	37.8	.450
13 500	431.09	803	1334	37.6	.480
13 670	436.19	.....	(1375)	.....	.510
12 000	386.09	.....	.....	.....	.535
BEAM 287					
0	26.29	24	22	52.5	0.010
1000	56.29	53	48	52.5	.020
2000	86.29	81	72	52.8	.030
3000	116.29	115	101	53.2	.050
3500	131.29	131	118	52.7	.060
4000	146.29	153	138	52.5	.065
4500	161.29	174	162	51.8	.070
5000	176.29	209	210	49.9	.090
6000	206.29	284	345	45.2	.130
7000	236.29	360	482	42.8	.170
8000	266.29	421	612	40.7	.215
9000	296.29	497	760	39.5	.265
10 000	326.29	552	887	38.8	.320
11 000	356.29	640	1022	38.5	.365
12 000	386.29	717	1172	37.9	.410
12 500	401.29	772	1266	37.9	.440
13 000	416.29	812	1348	37.6	.465
13 100	419.29	.....	(1504)	.....	.500
12 000	386.29	872	1723	33.6	.510

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 257					
0	25.88	31	28	52.5	0.010
1000	55.88	63	57	52.5	.020
2000	85.88	97	88	52.5	.035
3000	115.88	133	120	52.5	.050
4000	145.88	173	158	52.2	.060
5000	175.88	225	237	48.7	.090
6000	205.88	305	373	45.0	.120
7000	235.88	370	500	42.6	.165
8000	265.88	440	623	41.4	.205
9000	295.88	523	753	41.0	.250
10 000	325.88	597	895	40.0	.295
11 000	355.88	671	1014	39.8	.335
12 000	385.88	743	1131	39.6	.385
13 000	415.88	823	1243	39.8	.420
14 000	445.88	903	1373	39.7	.465
14 600	463.88	.....	(1460)	.....	.505
14 860	471.68	.....	(1527)	.....	.525
13 900	442.88	1045	1722	37.8	.530
BEAM 298					
0	26.29	27	20	57.8	0.010
1000	56.29	56	41	57.7	.025
2000	86.29	89	66	57.3	.035
3000	116.29	125	97	56.3	.050
4000	146.29	168	141	54.4	.065
5000	176.29	236	229	50.8	.095
6000	206.29	318	343	48.1	.130
7000	236.29	394	471	45.6	.175
8000	266.29	469	606	43.6	.220
9000	296.29	541	719	42.9	.260
10 000	326.29	610	837	42.4	.300
11 000	356.29	689	940	42.3	.345
12 000	386.29	762	1061	41.8	.385
13 000	416.29	863	1191	42.0	.430
14 000	446.29	937	1307	41.8	.470
15 000	476.29	1054	1464	41.9	.525
15 520	491.89	.....	(1560)	.....	.560
13 700	437.29	.....	.....	.....	.575
BEAM 299					
0	25.88	38	24	61.4	0.010
1000	55.88	70	50	58.3	.020
2000	85.88	107	77	58.2	.035
3000	115.88	145	108	57.3	.050
4000	145.88	187	149	55.6	.070
5000	175.88	250	229	52.2	.095
6000	205.88	326	328	49.8	.135
7000	235.88	401	463	46.4	.175
8000	265.88	479	588	44.9	.220
9000	295.88	566	708	44.4	.260
10 000	325.88	651	827	44.0	.305
11 000	355.88	728	930	43.7	.345
12 000	385.88	815	1058	43.5	.395
13 000	415.88	878	1176	42.7	.440
14 000	445.88	979	1328	42.4	.485
14 500	460.88	1058	1415	42.8	.520
15 000	475.88	1111	1508	42.4	.545
15 100	478.88	.....	(1615)	.....	.585
12 900	412.88	1241	2162	36.5	.615

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 318					
0	26.29	33	22	59.8	0.015
1000	56.29	68	48	58.5	.025
2000	86.29	102	75	57.6	.040
3000	116.29	141	101	58.3	.055
4000	146.29	184	133	58.0	.070
5000	176.29	242	184	56.8	.090
6000	206.29	313	284	52.4	.120
7000	236.29	389	383	50.4	.155
8000	266.29	463	494	48.4	.190
9000	296.29	536	588	47.7	.225
10 000	326.29	615	690	47.1	.260
11 000	356.29	681	786	46.4	.300
12 000	386.29	755	894	45.8	.340
13 000	416.29	837	991	45.8	.375
14 000	446.29	910	1085	45.6	.415
15 000	476.29	1012	1190	46.0	.460
16 000	506.29	1099	1294	45.9	.500
17 000	536.29	1225	1413	46.4	.550
17 500	551.29	1314	1530	46.2	.580
17 650	555.79	.....	(1566)	.....	.595
16 700	527.29	1406	1737	44.7	.615
BEAM 319					
0	26.29	31	23	57.2	0.010
2000	86.29	100	73	57.7	.035
3000	116.29	136	98	58.1	.050
4000	146.29	181	134	57.4	.060
5000	176.29	233	189	55.2	.085
6000	206.29	303	276	52.3	.115
7000	236.29	379	375	50.2	.150
8000	266.29	450	473	48.8	.185
9000	296.29	517	577	47.2	.220
10 000	326.29	588	678	46.5	.255
11 000	356.29	658	767	46.2	.290
12 000	386.29	726	862	45.7	.330
13 000	416.29	823	963	46.1	.370
14 000	446.29	890	1064	45.5	.405
15 000	476.29	976	1168	45.5	.445
16 000	506.29	1091	1298	45.7	.495
17 000	536.29	1266	1570	44.6	.560
16 000	506.29	1329	1811	42.3	.640
BEAM 320					
0	26.09	40	26	60.8	0.010
1000	56.09	72	57	56.0	.020
2000	86.09	110	86	56.1	.035
3000	116.09	149	117	56.1	.050
4000	146.09	195	159	55.0	.065
5000	176.09	256	231	52.6	.090
6000	206.09	327	315	50.9	.110
7000	236.09	399	414	49.1	.160
8000	266.09	472	530	47.1	.200
9000	296.09	546	638	46.1	.240
10 000	326.09	607	734	45.3	.270
11 000	356.09	677	852	44.3	.310
12 000	386.09	752	959	43.9	.350
13 000	416.09	841	1053	44.4	.395
14 000	446.09	926	1154	44.5	.435
15 000	476.09	1026	1270	44.7	.455
16 000	506.09	1137	1404	44.7	.520
16 500	521.09	.....	(1508)	.....	.560
16 600	524.09	.....	(1713)	.....	.590
15 400	488.09	1358	1910	41.5	.600

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 321					
0	26.29	28	23	54.5	0.010
1000	56.29	57	50	53.4	.020
2000	86.29	91	76	54.6	.035
3000	116.29	128	105	54.9	.045
4000	146.29	171	141	54.7	.060
5000	176.29	224	204	52.4	.080
6000	206.29	282	285	50.0	.100
7000	236.29	358	375	48.8	.140
8000	266.29	431	464	48.1	.170
9000	296.29	502	556	47.4	.205
10 000	326.29	566	649	46.6	.235
11 000	356.29	639	743	46.2	.270
12 000	386.29	702	835	45.7	.305
13 000	416.29	780	920	45.9	.340
14 000	446.29	851	1013	45.7	.375
15 000	476.29	939	1100	46.0	.415
16 000	506.29	1016	1196	45.9	.450
17 000	536.29	1114	1291	46.3	.490
17 620	554.89	.....	(1387)	.....	.520
18 000	566.29	1254	1491	45.7	.545
18 680	586.69	.....	(1669)	.....	.595
18 870	592.39	.....	(1808)	.....	.620
17 000	536.29	1557	2240	41.0	.655
BEAM 322					
0	26.09	30	24	55.3	0.010
1000	56.09	64	48	57.0	.025
2000	86.09	98	77	55.9	.035
3000	116.09	130	106	55.0	.050
4000	146.09	167	140	54.5	.065
5000	176.09	219	198	52.5	.080
6000	206.09	279	279	50.0	.115
7000	236.09	354	373	48.7	.150
8000	266.09	431	467	48.0	.180
9000	296.09	494	562	46.8	.210
10 000	326.09	550	670	45.1	.250
11 000	356.09	636	747	46.0	.285
12 000	386.09	698	831	45.7	.320
13 000	416.09	786	920	46.1	.355
14 000	446.09	857	1002	46.1	.390
15 000	476.09	941	1091	46.3	.425
16 000	506.09	1015	1174	46.4	.465
17 000	536.09	1103	1272	46.4	.500
18 000	566.09	1241	1393	47.1	.555
18 200	572.09	.....	(1484)	.....	.605
18 320	575.69	.....	(1549)	.....	.625
17 200	542.09	.....	.....	.....	.655
BEAM 323					
0	26.09	28	23	54.5	0.010
1000	56.09	63	49	56.1	.020
2000	86.09	91	76	54.6	.030
3000	116.09	128	107	54.4	.040
4000	146.09	168	141	54.4	.045
5000	176.09	217	202	51.8	.075
6000	206.08	280	285	49.6	.100
7000	236.09	349	348	50.1	.125
8000	266.09	414	459	47.4	.155
9000	296.09	490	531	48.0	.185
10 000	326.09	561	628	47.2	.225
11 000	356.09	627	717	46.7	.245
12 000	386.09	675	803	45.7	.290
13 000	416.09	755	879	46.2	.330
14 000	446.09	828	970	45.8	.360
15 000	476.09	921	1057	46.6	.400
16 000	506.09	1000	1146	46.6	.435
17 000	536.09	1092	1249	46.6	.475
18 000	566.09	1177	1337	46.8	.515
18 400	578.09	.....	(1409)	.....	.540
18 960	594.89	.....	(1635)	.....	.595
17 000	536.09	1406	2059	40.6	.625

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 249					
0	25.06	26	17	60.6	0.010
1000	55.06	53	41	60.7	.025
2000	85.06	93	68	57.8	.035
2500	100.06	111	84	56.9	.035
3000	115.06	133	104	56.1	.045
3500	130.06	152	120	55.8	.055
4000	145.06	185	186	49.8	.065
4500	160.06	306	578	34.6	.165
5000	175.06	339	696	32.7	.200
5500	190.06	396	862	31.5	.245
6000	205.06	440	997	30.6	.305
6300	169.06	408	913	30.9	.320
BEAM 250					
0	25.26	21	19	52.5	0.005
1000	55.26	60	39	60.6	.015
2000	85.26	90	65	58.0	.025
3000	115.26	122	92	56.9	.040
3500	130.26	143	111	56.2	.050
4000	145.26	168	145	53.6	.060
4500	160.26	270	485	35.7	.140
5000	175.26	294	585	33.4	.180
5500	190.26	370	846	30.4	.250
6000	205.26	404	979	29.2	.290
6450	218.76	.....	1091	.....	.350
4900	172.26	431	1542	21.9	.365
BEAM 251					
0	25.68	24	19	56.0	0.010
1000	55.68	51	41	55.2	.020
2000	85.68	81	65	55.6	.030
3000	115.68	109	91	54.5	.040
3500	130.68	127	109	53.8	.050
4000	145.68	152	149	50.5	.060
4500	160.68	259	544	32.3	.130
5000	175.68	294	670	30.5	.185
5500	190.68	324	814	28.5	.240
6000	205.68	366	973	27.3	.290
5000	175.68	365	1344	21.4	.320
BEAM 264					
0	25.88	21	17	55.1	0.010
1000	55.88	51	44	53.6	.025
2000	85.88	85	70	54.8	.035
3000	115.88	117	97	54.6	.045
4000	145.88	152	135	53.0	.060
4500	160.88	183	190	49.0	.075
5000	175.88	227	313	42.0	.105
5500	190.88	281	484	36.8	.140
6000	205.88	326	621	34.4	.180
7000	235.88	386	817	32.1	.240
8000	265.88	460	1034	30.8	.300
8500	280.88	503	1183	29.8	.335
8750	288.38	.....	1359	.....	.375
8780	289.28	.....	1403	.....	.385
8000	265.88	521	1362	27.7	.405
BEAM 265					
0	25.68	16	24	40.0	0.010
1000	55.68	49	48	50.4	.020
2000	85.68	78	75	50.9	.035
3000	115.68	107	101	51.5	.045
4000	145.68	146	140	51.1	.055
4500	160.68	172	185	48.0	.070
5000	175.68	235	291	44.7	.095
5500	190.68	286	422	40.4	.135
6000	205.68	322	530	37.8	.175
7000	235.68	394	752	34.4	.235
8000	265.68	466	988	32.0	.305
8500	280.68	.....	1101	.....	.335
7500	250.68	515	1373	27.3	.355
BEAM 266					
0	25.68	24	19	56.0	0.010
1000	55.68	55	44	55.5	.025
2000	85.68	85	68	55.4	.040
3000	115.68	119	96	55.3	.050
3500	130.68	132	111	54.4	.060
4000	145.68	159	133	54.4	.070
4500	160.68	179	168	51.6	.080
5000	175.68	256	349	42.3	.110
5500	190.68	290	456	38.9	.145
6000	205.68	327	579	36.1	.180
7000	235.68	406	822	33.1	.260
8000	265.68	489	1043	31.9	.330
8630	284.58	.....	1246	.....	.390
7600	253.68	549	1509	26.7	.395

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 276					
0	25.47	21	17	55.1	0.015
1000	55.47	75	27	73.6	.045
2000	85.47	107	53	66.9	.055
3000	115.47	136	75	64.4	.065
4000	145.47	168	104	61.7	.080
4500	160.47	189	130	59.2	.090
5000	175.47	208	159	56.7	.100
5500	190.47	239	198	54.7	.115
6000	205.47	278	274	50.3	.135
7000	235.47	357	487	42.3	.190
8000	265.47	426	627	40.4	.245
9000	295.47	475	776	37.9	.295
10 000	325.47	530	913	36.7	.345
11 000	355.47	593	1050	36.1	.395
11 910	382.77	.....	1157	.....	.445
11 930	383.37	.....	1168	.....	.455
10 500	340.47	601	1091	35.5	.460
BEAM 277					
0	25.68	21	21	50.1	0.005
1000	55.68	51	46	52.5	.015
2000	85.68	83	70	54.1	.025
3000	115.68	114	92	55.4	.035
4000	145.68	146	118	55.3	.050
4500	160.68	158	132	54.6	.055
5000	175.68	181	161	52.9	.065
5500	190.68	206	203	50.4	.075
6000	205.68	258	280	47.9	.095
7000	235.68	326	499	39.5	.155
8000	265.68	389	685	36.2	.205
9000	295.68	445	838	34.7	.260
10 000	325.68	501	986	33.7	.310
11 000	355.68	567	1137	33.3	.355
12 000	385.68	629	1297	32.7	.410
10 200	331.68	645	1730	27.1	.435
BEAM 278					
0	25.68	24	19	56.0	0.010
1000	55.68	53	48	52.5	.020
2000	85.68	83	72	53.5	.030
3000	115.68	115	97	54.2	.040
4000	145.68	149	123	54.7	.055
4500	160.68	167	142	54.1	.060
5000	175.68	191	168	53.2	.070
5500	190.68	218	200	52.1	.085
6000	205.68	251	258	49.4	.105
7000	235.68	348	489	41.6	.170
8000	265.68	404	682	37.2	.220
9000	295.68	476	838	36.2	.275
10 000	325.68	534	983	35.2	.320
11 000	355.68	607	1138	34.8	.380
11 170	360.78	.....	1202	.....	.415
10 700	346.68	617	1169	34.6	.415

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 288					
0	25.68	24	19	56.0	0.005
1000	55.68	61	39	61.0	.020
2000	85.68	95	65	59.4	.030
3000	115.68	125	84	59.9	.040
4000	145.68	157	106	59.7	.050
5000	175.68	212	174	55.0	.070
6000	205.68	296	318	48.2	.110
7000	235.68	368	472	43.8	.150
8000	265.68	431	617	41.1	.200
9000	295.68	484	756	39.0	.245
10 000	325.68	562	865	39.4	.290
11 000	355.68	602	983	38.0	.330
12 000	385.68	682	1099	38.3	.370
13 000	415.68	756	1262	37.5	.420
13 850	441.18	.....	1397	.....	.460
12 300	394.68	797	1409	36.1	.490
BEAM 289					
0	26.09	28	15	65.2	0.005
1000	56.09	63	34	64.9	.020
2000	86.09	93	60	60.7	.030
3000	116.09	126	87	59.1	.045
4000	146.09	159	118	57.4	.055
5000	176.09	204	178	53.4	.075
6000	206.09	271	291	48.2	.105
7000	236.09	347	465	42.7	.155
8000	266.09	416	619	40.2	.200
9000	296.09	478	774	38.2	.245
10 000	326.09	541	915	37.1	.290
11 000	356.09	609	1068	36.3	.340
12 000	386.09	678	1221	35.7	.390
12 800	410.09	.....	1542	.....	.470
12 000	386.09	784	1549	33.6	.480
BEAM 290					
0	26.29	23	17	57.5	0.010
1000	56.29	56	38	59.4	.020
2000	86.29	87	62	58.5	.030
3000	116.29	119	87	57.8	.045
4000	146.29	150	115	56.6	.055
5000	176.29	197	178	52.5	.075
6000	206.29	265	309	46.1	.105
7000	236.29	339	463	42.3	.155
8000	266.29	405	609	39.9	.200
9000	296.29	471	742	38.8	.240
10 000	326.29	528	877	37.6	.285
11 000	356.29	591	1005	37.0	.325
12 000	386.29	659	1138	36.7	.380
13 000	416.29	739	1320	35.9	.430
13 140	420.49	.....	1352	.....	.445
11 500	371.29	709	1268	35.9	.450

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 300					
0	25.68	19	17	52.5	0.010
1000	55.68	51	41	55.2	.015
2000	85.68	87	65	57.1	.030
3000	115.68	111	91	55.0	.040
4000	145.68	145	121	54.6	.050
5000	175.68	186	166	52.8	.070
6000	205.68	244	258	48.6	.095
7000	235.68	305	361	45.8	.130
8000	265.68	369	496	42.7	.170
9000	295.68	436	634	40.8	.215
10 000	325.68	502	752	40.0	.260
11 000	355.68	562	863	39.4	.290
12 000	385.68	611	956	39.0	.330
13 000	415.68	683	1072	38.9	.370
14 000	445.68	766	1193	39.1	.415
14 780	469.08	.....	1292	.....	.455
15 000	475.68	874	1436	37.9	.475
15 600	493.68	.....	1574	.....	.515
15 700	496.68	.....	1644	.....	.545
13 700	436.68	997	2323	30.0	.550
BEAM 301					
0	25.88	24	21	53.6	0.010
1000	55.88	58	43	56.5	.020
2000	85.88	84	65	56.5	.030
3000	115.88	114	87	56.7	.040
4000	145.88	151	116	56.6	.055
5000	175.88	192	164	53.9	.070
6000	205.88	252	241	51.1	.100
7000	235.88	318	338	48.5	.130
8000	265.88	387	467	45.3	.170
9000	295.88	447	600	42.7	.210
10 000	325.88	507	709	41.7	.250
11 000	355.88	566	817	40.9	.290
12 000	385.88	629	938	40.1	.330
13 000	415.88	692	1058	39.6	.370
14 000	445.88	778	1198	39.3	.410
14 500	460.88	816	1282	38.9	.440
14 870	471.98	.....	1371	.....	.460
14 870	471.98	.....	1462	.....	.475
14 900	472.88	.....	1557	.....	.490
13 800	439.88	956	1915	33.3	.525
BEAM 302					
0	25.68	19	15	55.5	0.010
1000	55.68	60	38	61.2	.020
2000	85.68	92	63	59.3	.035
3000	115.68	125	89	58.6	.045
4000	145.68	159	116	57.8	.055
5000	175.68	209	164	56.0	.075
6000	205.68	264	243	52.1	.100
7000	235.68	340	338	50.1	.135
8000	265.68	402	463	46.5	.175
9000	295.68	470	597	44.1	.215
10 000	325.68	531	692	43.4	.260
11 000	355.68	595	805	42.5	.300
12 000	385.68	654	911	41.8	.340
13 000	415.68	724	1029	41.3	.375
14 000	445.68	794	1142	41.0	.420
14 800	469.68	.....	1426	.....	.480
14 000	445.68	920	1585	36.7	.490
BEAM 312					
0	26.29	21	17	55.1	0.010
1000	56.29	51	48	51.5	.020
2000	86.29	75	68	52.5	.030
3000	116.29	109	91	54.5	.040
4000	146.29	141	115	55.0	.050
5000	176.29	177	145	55.0	.065
6000	206.29	219	197	52.6	.080
7000	236.29	277	268	50.8	.105
8000	266.29	340	376	47.5	.140
9000	296.29	400	485	45.2	.175
10 000	326.29	439	590	42.7	.205
11 000	356.29	516	694	42.7	.240
12 000	386.29	577	800	41.9	.270
13 000	416.29	632	885	41.7	.305
14 000	446.29	686	971	41.4	.330
15 000	476.29	745	1060	41.3	.365
16 000	506.29	814	1152	41.4	.410
17 000	536.29	880	1268	41.0	.430
18 000	566.29	.....	1487	.....	.500
16 200	512.29	1008	1853	35.2	.510
BEAM 313					
0	26.71	24	15	61.5	0.010
1000	56.71	56	46	54.9	.020
2000	86.71	88	72	55.0	.025
3000	116.71	117	96	54.8	.040
4000	146.71	151	123	55.1	.050
5000	176.71	190	156	55.0	.060
6000	206.71	231	205	53.0	.080
7000	236.71	284	272	51.1	.100
8000	266.71	343	357	49.0	.135
9000	296.71	400	451	47.0	.165
10 000	326.71	455	550	45.3	.200
11 000	356.71	508	646	44.0	.235
12 000	386.71	567	745	43.2	.270
13 000	416.71	614	827	42.6	.300
14 000	446.71	665	918	42.0	.330
15 000	476.71	718	1010	41.6	.365
16 000	506.71	787	1103	41.6	.400
17 000	536.71	844	1195	41.4	.435
18 000	566.71	914	1272	41.8	.475
18 420	579.31	.....	1345	.....	.500
16 600	524.71	919	1277	41.8	.520
BEAM 314					
0	25.88	21	15	58.1	0.005
1000	55.88	50	34	63.7	.025
2000	85.88	86	58	59.8	.035
3000	115.88	114	79	59.0	.045
4000	145.88	148	106	56.2	.055
5000	175.88	180	135	57.1	.070
6000	205.88	225	179	55.7	.085
7000	235.88	274	246	52.7	.110
8000	265.88	330	335	49.6	.140
9000	295.88	391	441	47.0	.170
10 000	325.88	457	552	45.3	.200
11 000	355.88	509	641	44.2	.235
12 000	385.88	564	730	43.6	.270
13 000	415.88	616	819	42.9	.300
14 000	445.88	670	904	42.6	.335
15 000	475.88	735	1003	42.3	.370
16 000	505.88	805	1106	42.1	.410
17 000	535.88	874	1222	41.7	.450
17 770	558.98	940	1325	41.5	.500
16 500	520.88	927	1274	42.1	.525

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 324					
0	25.88	24	17	58.6	0.010
1000	55.88	58	39	59.7	.015
2000	85.88	86	63	57.8	.025
3000	115.88	118	85	58.2	.040
4000	145.88	148	109	57.6	.050
5000	175.88	178	138	56.3	.065
6000	205.88	231	195	54.3	.085
7000	235.88	287	256	52.9	.110
8000	265.88	341	323	51.4	.130
9000	295.88	402	412	49.4	.160
10 000	325.88	458	516	47.0	.195
11 000	355.88	512	602	45.9	.230
12 000	385.88	563	684	45.2	.255
13 000	415.88	614	766	44.5	.285
14 000	445.88	666	841	44.2	.315
15 000	475.88	723	923	43.9	.350
16 000	505.88	780	998	43.9	.380
17 000	535.88	833	1074	43.7	.410
18 000	565.88	890	1152	43.6	.440
19 000	595.88	966	1241	43.8	.475
20 000	625.88	1034	1330	43.7	.510
21 000	655.88	1102	1419	43.7	.545
21 350	666.38	.....	1499	.....	.580
21 360	666.68	.....	1603	.....	.600
18 300	574.88	1191	1949	37.9	.615
BEAM 325					
0	26.50	23	17	57.5	0.010
1000	56.50	56	43	56.5	.025
2000	86.50	84	62	57.6	.035
3000	116.50	116	84	58.0	.050
4000	146.50	145	109	57.0	.060
5000	176.50	184	142	56.5	.075
6000	206.50	223	190	54.0	.090
7000	236.50	282	260	52.0	.120
8000	266.50	330	333	49.8	.145
9000	296.50	384	410	48.3	.175
10 000	326.50	440	506	46.5	.200
11 000	356.50	488	598	45.0	.235
12 000	386.50	538	677	44.3	.260
13 000	416.50	588	757	43.7	.295
14 000	446.50	640	838	43.3	.325
15 000	476.50	687	913	42.9	.355
16 000	506.50	742	991	42.8	.385
17 000	536.50	797	1077	42.5	.420
18 000	566.50	850	1154	42.4	.450
19 000	596.50	919	1231	42.8	.485
20 000	626.50	990	1325	42.8	.525
20 200	632.50	.....	1374	.....	.540
20 430	639.40	.....	1458	.....	.560
20 730	648.40	.....	1528	.....	.590
18 000	566.50	1130	2058	35.5	.605
BEAM 326					
0	26.09	31	15	67.6	0.010
1000	56.09	67	38	63.9	.020
2000	86.09	99	62	61.5	.035
3000	116.09	131	84	60.9	.045
4000	146.09	158	106	59.9	.060
5000	176.09	202	140	59.1	.070
6000	206.09	244	188	56.4	.090
7000	236.09	305	258	54.2	.115
8000	266.09	365	335	52.1	.140
9000	296.09	430	441	49.3	.170
10 000	326.09	481	528	47.7	.200
11 000	356.09	546	627	46.5	.235
12 000	386.09	591	709	45.5	.260
13 000	416.09	651	795	45.0	.295
14 000	446.09	701	872	44.5	.325
15 000	476.09	756	959	44.1	.355
16 000	506.09	821	1043	44.0	.390
17 000	536.09	880	1132	43.7	.420
18 000	566.09	939	1212	43.6	.450
19 000	596.09	1029	1326	43.7	.495
19 450	609.59	.....	1397	.....	.520
19 650	615.59	.....	1463	.....	.530
19 920	623.69	.....	1564	.....	.550
17 900	563.09	1224	1901	39.2	.590

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 252					
0	25.26	16	17	47.9	0.005
1000	55.26	48	43	52.5	.020
2000	85.26	70	62	52.9	.035
2500	100.26	87	75	53.7	.040
3000	115.26	100	87	53.6	.045
3500	130.26	120	109	52.5	.055
4000	145.26	181	262	40.9	.085
4500	160.26	271	506	34.9	.155
5000	175.26	305	631	32.6	.195
5500	190.26	354	786	31.1	.245
6000	205.26	387	889	30.3	.285
6310	214.56	.....	1065	.....	.335
4300	154.26	417	1474	22.1	.355
BEAM 253					
0	25.47	19	21	47.5	0.010
1000	55.47	49	43	53.0	.025
2000	85.47	72	63	53.2	.035
2500	100.47	90	72	55.6	.040
3000	115.47	108	80	57.5	.045
3500	130.47	126	99	56.1	.055
4000	145.47	174	227	43.4	.075
4500	160.47	233	378	38.1	.120
5000	175.47	283	521	35.2	.180
5500	190.47	345	742	31.8	.240
6000	205.47	385	923	29.5	.290
5050	176.97	425	1610	20.0	.345
BEAM 254					
0	25.47	17	19	46.9	0.010
1000	55.47	42	41	50.7	.020
2000	85.47	70	63	52.5	.035
2500	100.47	85	79	51.9	.040
3000	115.47	102	97	51.2	.050
3500	130.47	118	118	50.0	.060
4000	145.47	165	191	46.3	.080
4500	160.47	235	421	35.8	.135
5000	175.47	282	591	32.3	.190
5500	190.47	317	762	29.4	.230
6000	205.47	359	1001	26.4	.285
4950	173.97	396	1779	18.2	.360

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 267					
0	25.88	16	17	47.9	0.005
1000	55.88	45	38	54.3	.015
2000	85.88	68	60	53.3	.030
3000	115.88	90	79	53.4	.040
3500	130.88	113	96	54.2	.050
4000	145.88	125	109	53.4	.055
4500	160.88	152	147	50.8	.065
5000	175.88	184	221	45.5	.080
6000	205.88	289	573	33.5	.155
7000	235.88	348	783	30.7	.220
8000	265.88	420	974	30.1	.280
9000	295.88	502	1251	28.6	.350
9110	299.18	.....	1356	.....	.380
7700	256.88	532	1718	23.6	.390
BEAM 268					
0	25.68	16	22	41.9	0.010
1000	55.68	38	46	45.4	.015
2000	85.68	62	67	48.3	.030
3000	115.68	89	91	49.4	.040
4000	145.68	120	111	51.9	.050
4500	160.68	139	132	51.2	.060
5000	175.68	167	181	48.1	.075
5500	190.68	233	368	38.7	.120
6000	205.68	274	480	36.3	.150
7000	235.68	346	699	33.1	.225
8000	265.68	404	882	31.4	.285
9000	295.68	467	1072	30.3	.350
7650	255.18	429	1010	29.8	.380
BEAM 269					
0	25.68	17	14	54.1	0.010
1000	55.68	.....	.....	.....	.....
2000	85.68	65	48	57.8	.030
3000	115.68	92	68	57.5	.045
3500	130.68	107	84	55.9	.050
4000	145.68	122	101	54.7	.055
4500	160.68	136	125	52.1	.065
5000	175.68	167	178	48.4	.075
6000	205.68	268	462	36.8	.135
7000	235.68	358	726	33.0	.210
8000	265.68	423	923	31.4	.275
9000	295.68	484	1092	30.7	.330
10 000	325.68	545	1255	30.3	.390
10 270	333.78	.....	1284	.....	.420
7650	255.18	476	1104	30.1	.425

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 279					
0	25.47	19	15	55.5	0.010
1000	55.47	47	36	56.7	.020
2000	85.47	69	53	56.6	.030
3000	115.47	96	77	55.4	.045
4000	145.47	130	106	55.0	.055
4500	160.47	154	135	53.4	.065
5000	175.47	178	168	51.5	.080
5500	190.47	208	226	47.9	.095
6000	205.47	246	294	45.6	.115
7000	235.47	316	499	38.8	.165
8000	265.47	379	674	36.0	.215
9000	295.47	440	834	34.5	.265
10 000	325.47	495	964	33.9	.310
11 000	355.47	545	1094	33.3	.350
12 000	385.47	602	1248	32.5	.395
12 380	396.87	.....	1325	.....	.435
10 100	328.47	574	1229	31.8	.440
BEAM 280					
0	25.88	16	19	45.3	0.010
1000	55.88	30	32	48.5	.020
2000	85.88	53	55	49.3	.030
3000	115.88	82	77	51.6	.040
4000	145.88	109	99	52.5	.055
5000	175.88	152	150	50.3	.075
5500	190.88	183	203	47.4	.090
6000	205.88	217	270	44.6	.110
7000	235.88	295	501	37.0	.165
8000	265.88	361	672	34.9	.220
9000	295.88	413	810	33.8	.270
10 000	325.88	468	949	33.0	.315
11 000	355.88	526	1115	32.1	.370
11 430	368.78	.....	1268	.....	.415
9950	324.38	584	1609	26.7	.420
BEAM 281					
0	25.47	17	14	54.1	0.010
1000	55.47	43	31	57.9	.020
2000	85.47	69	44	60.9	.030
3000	115.47	99	65	60.4	.045
3500	130.47	112	75	60.0	.055
4000	145.47	124	94	56.9	.060
4500	160.47	141	116	54.8	.065
5000	175.47	160	135	54.2	.075
6000	205.47	224	263	46.0	.110
7000	235.47	317	485	39.5	.170
8000	265.47	380	627	37.8	.225
9000	295.47	433	752	36.6	.265
10 000	325.47	495	891	35.7	.315
11 000	355.47	549	1022	34.9	.365
11 740	377.67	.....	1215	.....	.425
10 200	331.47	681	1901	27.4	.475

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 291					
0	25.88	17	15	52.5	0.010
1000	55.88	42	32	56.6	.015
2000	85.88	68	50	57.6	.025
3000	115.88	93	72	56.4	.035
4000	145.88	129	94	57.9	.050
5000	175.88	160	132	54.7	.060
6000	205.88	225	241	48.3	.100
7000	235.88	301	414	42.1	.145
8000	265.88	353	533	39.9	.185
9000	295.88	411	675	37.9	.230
10 000	325.88	469	815	36.5	.270
11 000	355.88	517	945	35.4	.310
12 000	385.88	566	1082	34.4	.355
13 000	415.88	621	1277	32.7	.410
13 220	422.48	.....	1504	.....	.460
11 700	376.88	697	1853	27.3	.470
BEAM 292					
0	26.09	14	17	44.3	0.010
1000	56.09	35	41	45.9	.020
2000	86.09	57	63	47.5	.030
3000	116.09	87	80	52.2	.040
4000	146.09	117	109	51.8	.050
5000	176.09	153	147	51.0	.070
6000	206.09	200	214	48.3	.090
7000	236.09	282	397	41.5	.135
8000	266.09	354	542	39.5	.180
9000	296.09	410	675	37.8	.225
10 000	326.09	466	802	36.8	.265
11 000	356.09	529	930	36.3	.310
12 000	386.09	583	1058	35.5	.355
13 000	416.09	656	1296	33.9	.415
11 700	377.09	744	1945	27.7	.465
BEAM 293					
0	26.29	17	17	49.5	0.010
1000	56.29	47	31	60.2	.020
2000	86.29	69	50	58.0	.030
3000	116.29	101	70	59.0	.040
4000	146.29	127	92	58.0	.055
5000	176.29	164	135	54.8	.070
6000	206.29	213	227	48.4	.095
7000	236.29	287	390	42.4	.140
8000	266.29	355	532	40.0	.185
9000	296.29	421	679	38.3	.235
10 000	326.29	475	791	37.5	.275
11 000	356.29	530	915	36.7	.315
12 000	386.29	589	1029	36.4	.365
13 000	416.29	649	1147	36.1	.405
13 600	434.29	.....	1315	.....	.475
11 700	377.29	752	1841	29.0	.510

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 303					
0	25.47	19	17	52.5	0.005
1000	55.47	40	32	55.3	.015
2000	85.47	64	53	54.6	.030
3000	115.47	88	70	55.7	.040
4000	145.47	120	94	56.0	.050
5000	175.47	166	147	53.0	.065
6000	205.47	221	234	48.5	.095
7000	235.47	274	326	45.7	.120
8000	265.47	341	467	42.2	.170
9000	295.47	398	583	40.6	.200
10 000	325.47	451	713	38.8	.240
11 000	355.47	503	831	37.7	.280
12 000	385.47	549	944	36.8	.320
13 000	415.47	587	1039	36.1	.350
14 000	445.47	635	1156	35.4	.390
15 000	475.47	671	1274	34.5	.430
15 820	500.07	.....	1549	.....	.490
14 500	460.47	841	2291	26.9	.575
BEAM 304					
0	25.47	23	24	49.3	0.010
1000	55.47	48	41	54.2	.020
2000	85.47	75	62	54.7	.030
3000	115.47	101	82	55.2	.040
4000	145.47	128	109	54.0	.050
5000	175.47	170	154	52.5	.070
6000	205.47	223	243	47.9	.090
7000	235.47	275	337	44.9	.120
8000	265.47	340	484	41.3	.160
9000	295.47	394	593	39.9	.200
10 000	325.47	444	721	38.1	.240
11 000	355.47	495	834	37.4	.275
12 000	385.47	544	928	36.7	.310
13 000	415.47	593	1044	36.2	.350
14 000	445.47	644	1159	35.7	.385
15 000	475.47	702	1285	35.3	.430
15 710	496.77	.....	1564	.....	.490
13 750	437.97	811	2050	28.3	.520
BEAM 305					
0	26.09	21	14	59.7	0.005
1000	56.09	45	31	59.1	.015
2000	86.09	71	55	56.5	.025
3000	116.09	96	75	56.0	.040
4000	146.09	122	101	54.7	.050
5000	176.09	159	138	53.5	.060
6000	206.09	203	193	51.2	.080
7000	236.09	254	284	47.2	.110
8000	266.09	308	407	43.1	.140
9000	296.09	376	535	41.2	.185
10 000	326.09	425	656	39.3	.225
11 000	356.09	473	757	38.5	.260
12 000	386.09	522	862	37.7	.300
13 000	416.09	573	961	37.3	.330
14 000	446.09	627	1067	37.0	.370
15 000	476.09	675	1166	36.7	.410
16 000	506.09	736	1294	36.2	.450
16 930	533.99	.....	1503	.....	.510
14 350	456.59	824	1834	31.0	.540

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 315					
0	26.09	19	22	46.4	0.010
1000	56.09	40	30	50.6	.020
2000	86.09	62	56	52.5	.030
3000	116.09	93	80	53.7	.040
4000	146.09	124	99	55.6	.055
5000	176.09	156	132	54.2	.070
6000	206.09	197	176	52.8	.085
7000	236.09	252	250	50.2	.110
8000	266.09	304	337	47.4	.140
9000	296.09	360	436	45.2	.170
10 000	326.09	406	530	43.4	.200
11 000	356.09	462	639	42.0	.235
12 000	386.09	506	728	41.0	.265
13 000	416.09	558	819	40.5	.295
14 000	446.09	609	911	40.1	.330
15 000	476.09	661	1002	39.8	.360
16 000	506.09	716	1082	39.8	.395
17 000	536.09	771	1168	39.8	.425
18 000	566.09	820	1260	39.4	.455
18 940	594.29	.....	1470	.....	.505
16 800	530.09	955	1945	32.9	.545
BEAM 316					
0	26.29	19	14	57.1	0.010
1000	56.29	42	29	58.9	.020
2000	86.29	66	48	57.8	.030
3000	116.29	92	63	59.3	.040
4000	146.29	123	85	59.2	.050
5000	176.29	151	118	56.2	.065
6000	206.29	196	162	54.7	.085
7000	236.29	250	238	51.3	.105
8000	266.29	306	337	47.6	.135
9000	296.29	365	444	45.2	.170
10 000	326.29	416	538	43.6	.205
11 000	356.29	467	639	42.2	.240
12 000	386.29	515	733	41.3	.270
13 000	416.29	563	824	40.6	.305
14 000	446.29	613	915	40.1	.335
15 000	476.29	664	1003	39.8	.365
16 000	506.29	722	1089	39.8	.400
17 000	536.29	771	1174	39.6	.435
18 000	566.29	831	1262	39.7	.465
18 880	592.69	.....	1561	.....	.535
16 600	524.29	1017	2542	28.6	.595
BEAM 317					
0	26.50	16	17	47.9	0.010
1000	56.50	43	41	51.3	.020
2000	86.50	66	58	53.3	.030
3000	116.50	93	80	53.7	.040
4000	146.50	119	104	53.4	.050
5000	176.50	156	130	54.6	.060
6000	206.50	199	198	50.1	.080
7000	236.50	245	272	47.4	.110
8000	266.50	299	374	44.4	.140
9000	296.50	344	463	42.7	.160
10 000	326.50	398	559	41.6	.190
11 000	356.50	445	662	40.1	.235
12 000	386.50	488	752	39.4	.270
13 000	416.50	537	839	39.0	.300
14 000	446.50	589	926	38.9	.330
15 000	476.50	639	1014	38.6	.360
16 000	506.50	695	1106	38.6	.395
17 000	536.50	753	1207	38.4	.430
18 000	566.50	809	1309	38.3	.465
16 900	533.50	962	2142	31.0	.575

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 327					
0	25.88	17	15	52.5	0.010
1000	55.88	45	41	52.5	.020
2000	85.88	74	53	54.0	.030
3000	115.88	103	85	54.9	.040
4000	145.88	133	108	55.2	.055
5000	175.88	171	137	55.6	.070
6000	205.88	213	191	52.7	.085
7000	235.88	260	253	50.6	.100
8000	265.88	311	326	48.8	.130
9000	295.88	368	424	46.4	.160
10 000	325.88	416	520	44.4	.185
11 000	355.88	474	631	42.9	.220
12 000	385.88	522	715	42.2	.245
13 000	415.88	584	805	42.1	.280
14 000	445.88	629	880	41.7	.305
15 000	475.88	681	974	41.1	.340
16 000	505.88	730	1051	41.0	.365
17 000	535.88	780	1142	40.6	.400
18 000	565.88	847	1230	40.4	.430
19 000	595.88	926	1398	39.8	.475
20 000	625.88	1004	1597	38.6	.520
18 000	565.88	1102	2275	32.6	.590
BEAM 328					
0	25.88	21	17	55.1	0.010
1000	55.88	43	38	53.1	.020
2000	85.88	72	60	54.4	.030
3000	115.88	100	79	55.9	.045
4000	145.88	130	104	55.5	.060
5000	175.88	164	128	56.1	.070
6000	205.88	204	169	54.6	.090
7000	235.88	253	221	53.3	.110
8000	265.88	304	294	50.8	.155
9000	295.88	368	391	48.5	.165
10 000	325.88	427	496	46.3	.200
11 000	355.88	479	585	45.0	.230
12 000	385.88	532	670	44.3	.260
13 000	415.88	585	759	43.5	.290
14 000	445.88	635	838	43.1	.320
15 000	475.88	689	916	42.9	.355
16 000	505.88	750	1002	42.8	.380
17 000	535.88	803	1079	42.7	.415
18 000	565.88	862	1166	42.5	.445
19 000	595.88	923	1267	42.2	.480
20 000	625.88	1000	1397	41.7	.520
20 420	638.48	.....	1656	.....	.585
18 350	576.38	1054	1561	40.3	.610
BEAM 246					
0	25.47	26	17	60.6	0.010
1000	55.47	58	41	58.6	.020
2000	85.47	84	63	57.2	.030
3000	115.47	114	87	56.7	.040
4000	145.47	148	120	55.3	.055
5000	175.47	234	342	40.6	.100
6000	205.47	353	696	33.7	.245
7000	235.47	.....	1253	.....	.350
5400	187.47	486	2265	17.7	.490

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 247					
0	25.47	24	15	61.5	0.010
1000	55.47	55	36	60.2	.020
2000	85.47	82	56	59.4	.030
3000	115.47	113	84	57.3	.045
4000	145.47	143	113	55.8	.055
5000	175.47	256	576	31.6	.125
6000	205.47	375	1005	27.2	.235
6800	229.47	.....	1256	.....	.355
4700	166.47	468	2487	15.9	.440
BEAM 248					
0	25.68	13	10	56.8	0.010
1000	55.68	35	22	61.3	.025
2000	85.68	58	44	56.9	.035
3000	115.68	88	62	58.5	.045
4000	145.68	119	85	58.4	.055
5000	175.68	249	484	33.9	.150
6000	205.68	336	800	29.6	.250
6380	217.08	.....	868	.....	.320
5000	175.68	321	793	28.8	.320
BEAM 270					
0	26.09	11	10	52.5	0.005
1000	56.09	26	22	54.6	.015
2000	86.09	43	46	48.6	.030
3000	116.09	65	68	48.7	.040
4000	146.09	86	96	47.3	.055
5000	176.09	138	214	39.1	.080
6000	206.09	215	424	33.6	.135
7000	236.09	291	716	28.9	.210
8000	266.09	345	911	27.5	.265
9000	296.09	403	1156	25.8	.320
9360	306.89	.....	1258	.....	.375
7750	258.59	433	1578	21.6	.380

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 271					
0	25.88	15	9	62.8	0.010
1000	55.88	35	27	56.5	.020
2000	85.88	55	44	55.5	.030
3000	115.88	72	68	51.4	.040
4000	145.88	97	96	50.2	.050
5000	175.88	137	145	48.6	.070
6000	205.88	210	379	35.7	.130
7000	235.88	265	588	31.0	.190
8000	265.88	320	769	29.3	.260
9000	295.88	365	815	30.9	.340
8310	275.18	375	827	31.2	.480
BEAM 272					
0	26.09	11	14	44.6	0.010
1000	56.09	27	31	46.5	.020
2000	86.09	42	72	36.7	.030
3000	116.09	64	96	40.0	.040
4000	146.09	99	109	47.7	.050
5000	176.09	129	137	48.6	.060
6000	206.09	214	338	38.7	.105
7000	236.09	295	544	35.2	.180
8000	266.09	305	781	28.1	.250
9000	296.09	357	971	26.9	.300
9700	317.09	.....	1115	.....	.350
7550	252.59	435	1595	21.4	.390
BEAM 282					
0	26.09	16	15	50.9	0.010
1000	56.09	30	38	44.5	.020
2000	86.09	48	60	44.7	.030
3000	116.09	73	82	47.0	.040
4000	146.09	94	106	47.0	.050
5000	176.09	122	133	47.8	.060
6000	206.09	165	195	45.8	.080
7000	236.09	236	379	38.3	.130
8000	266.09	304	583	34.3	.185
9000	296.09	356	744	32.4	.230
10 000	326.09	409	895	31.4	.280
11 000	356.09	459	1022	31.0	.330
12 000	386.09	517	1205	30.0	.380
10 650	345.59	605	2241	21.2	.470

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 283					
0	26.09	15	10	60.4	0.010
1000	56.09	39	29	57.6	.020
2000	86.09	61	50	54.8	.030
3000	116.09	82	72	55.0	.040
4000	146.09	114	97	53.9	.050
5000	176.09	141	123	53.4	.065
6000	206.09	189	179	51.4	.085
7000	236.09	240	359	40.1	.130
8000	266.09	329	550	37.4	.180
9000	296.09	393	705	35.8	.240
10 000	326.09	444	850	34.3	.280
11 000	356.09	497	997	33.3	.330
12 000	386 09	553	1162	32.2	.380
12 620	404.69	.....	1303	.....	.440
10 300	335.09	606	1815	25.0	.440
BEAM 284					
0	25.88	14	22	38.5	0.010
1000	55.88	31	48	39.2	.020
2000	85.88	50	68	42.3	.035
3000	115.88	73	91	44.6	.045
4000	145.88	100	116	46.2	.055
5000	175.88	129	152	45.9	.065
6000	205.88	168	209	44.5	.085
7000	235.88	239	393	37.8	.135
8000	265.88	314	602	34.3	.195
9000	295.88	367	756	32.7	.255
10 000	325.88	429	901	32.2	.285
11 000	355.88	476	1046	31.3	.330
12 000	385.88	547	1198	31.4	.385
12 200	391.88	.....	1308	.....	.435
10 400	337.88	583	1708	25.4	.435
BEAM 294					
0	25.88	19	15	55.5	0.010
1000	55.88	43	34	55.8	.020
2000	85.88	69	53	56.6	.030
3000	115.88	98	75	56.5	.040
4000	145.88	122	97	55.7	.050
5000	175.88	152	125	54.8	.070
6000	205.88	191	176	52.1	.090
7000	235.88	263	325	44.8	.130
8000	265.88	323	496	39.4	.170
9000	295.88	377	690	37.1	.220
10 000	325.88	441	821	34.9	.265
11 000	355.88	491	945	34.2	.300
12 000	385.88	545	1106	33.0	.350
13 000	415.88	593	1197	33.1	.380
14 000	445.88	651	1368	32.2	.455
14 670	465.98	.....	1487	.....	.470
12 170	390.98	707	2072	25.4	.490
BEAM 295					
0	26.29	24	14	63.1	0.010
1000	56.29	47	32	59.5	.020
2000	86.29	71	55	56.5	.030
3000	116.29	101	77	56.7	.040
4000	146.29	126	103	55.1	.050
5000	176.29	152	128	54.3	.060
6000	206.29	192	186	50.8	.080
7000	236.29	265	356	42.7	.120
8000	266.29	321	494	39.4	.160
9000	296.29	373	622	37.5	.200
10 000	326.29	417	773	35.0	.250
11 000	356.29	458	891	34.0	.280
12 000	386,29	512	1014	33.6	.320
13 000	416.29	556	1130	33.0	.360
14 000	446.29	620	1289	32.5	.410
14 380	457.69	.....	1410	.....	.460
12 200	392.29	679	2140	24.1	.475
BEAM 296					
0	26.29	24	17	58.6	0.010
1000	56.29	48	34	58.6	.020
2000	86.29	73	56	56.7	.030
3000	116.29	101	79	56.1	.040
4000	146.29	128	106	54.6	.050
5000	176.29	162	142	53.3	.060
6000	206.29	198	188	51.3	.080
7000	236.29	275	311	47.0	.120
8000	266.29	344	458	42.9	.160
9000	296.29	402	607	39.9	.210
10 000	326.29	462	745	38.3	.250
11 000	356.29	514	877	36.9	.290
12 000	386.29	562	1005	35.9	.330
13 000	416.29	613	1126	35.2	.370
14 000	446.29	671	1294	34.2	.420
14 100	449.29	.....	1453	.....	.460
12 000	386.29	691	1923	26.5	.470
BEAM 306					
0	26.09	24	17	58.6	0.010
1000	56.09	47	38	55.4	.020
2000	86.09	75	60	55.5	.030
3000	116.09	106	85	55.4	.040
4000	146.09	133	111	54.5	.050
5000	176.09	168	145	53.6	.070
6000	206.09	202	186	52.1	.085
7000	236.09	272	292	48.2	.110
8000	256.09	340	410	45.4	.150
9000	296.09	403	544	42.6	.190
10 000	326.09	463	662	41.2	.230
11 000	356.09	532	800	39.9	.270
12 000	386.09	588	906	39.3	.310
13 000	416.09	638	1005	38.8	.345
14 000	446.09	706	1126	38.5	.390
15 000	476.09	770	1272	37.7	.430
16 000	506.09	862	1538	35.9	.490
16 450	519.59	.....	1692	.....	.550
13 450	429.59	956	2393	28.5	.570

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 307					
0	26.50	24	15	61.5	0.010
1000	56.50	53	39	57.4	.020
2000	86.50	77	58	57.0	.030
3000	116.50	98	79	55.3	.040
4000	146.50	124	103	54.7	.050
5000	176.50	154	128	54.6	.060
6000	206.50	184	171	51.8	.075
7000	236.50	226	243	48.2	.095
8000	266.50	283	340	44.7	.125
9000	296.50	341	489	41.0	.160
10 000	326.50	388	624	38.3	.200
11 000	356.50	441	769	36.5	.240
12 000	386.50	491	896	35.4	.275
13 000	416.50	541	1014	34.8	.310
14 000	446.50	593	1149	34.0	.350
15 000	476.50	652	1299	33.4	.395
16 000	506.50	715	1547	31.6	.450
16 070	508.60	.....	1728	.....	.....
14 450	460.00	823	2528	24.6	.600
BEAM 308					
0	26.09	10	09	52.5	0.005
1000	56.09	24	21	53.6	.015
2000	86.09	37	31	54.7	.025
3000	116.09	53	39	57.4	.035
4000	146.09	66	53	55.4	.045
5000	176.09	83	70	54.1	.060
6000	206.09	99	92	51.7	.075
7000	236.09	130	142	47.7	.100
8000	266.09	156	205	43.2	.130
9000	296.09	188	287	39.5	.175
10 000	326.09	215	373	36.6	.215
11 000	356.09	243	443	35.5	.255
12 000	386.09	266	506	34.4	.290
13 000	416.09	294	574	33.9	.325
14 000	446.09	328	651	33.5	.365
15 000	476.09	357	723	33.1	.405
16 000	506.09	395	846	31.8	.460
13 800	440.09	552	2364	19.0	.555
BEAM 309					
0	27.31	40	42	48.8	0.020
1000	57.31	60	58	50.8	.030
2000	87.31	93	89	51.1	.045
3000	117.31	126	122	50.9	.065
4000	147.31	165	163	50.2	.080
5000	177.31	205	211	49.3	.100
6000	207.31	240	251	48.9	.110
7000	237.31	278	299	48.2	.125
8000	267.31	320	352	47.6	.145
9000	297.31	363	425	46.0	.165
10 000	327.31	417	525	44.3	.200
11 000	357.31	474	622	43.2	.230
12 000	387.31	526	732	41.8	.270
13 000	417.31	575	814	41.4	.300
14 000	447.31	625	898	41.0	.330
15 000	477.31	677	982	40.8	.360
16 000	507.31	726	1070	40.4	.390
17 000	537.31	777	1166	40.0	.420
18 000	567.31	835	1254	40.0	.460
18 800	591.31	.....	.....	.....	.500
15 650	496.81	802	1202	40.0	.510

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 310					
0	25.88	26	19	58.0	0.010
1000	55.88	55	41	57.2	.020
2000	85.88	84	60	58.4	.030
3000	115.88	114	85	57.3	.040
4000	145.88	145	106	57.7	.050
5000	175.88	174	133	56.7	.060
6000	205.88	212	176	54.7	.070
7000	235.88	263	246	51.7	.095
8000	265.88	319	326	49.5	.130
9000	295.88	385	429	47.3	.155
10 000	325.88	446	566	44.0	.200
11 000	355.88	505	675	42.8	.230
12 000	385.88	558	779	41.7	.270
13 000	415.88	615	880	41.1	.310
14 000	445.88	670	976	40.7	.340
15 000	475.88	721	1072	40.2	.370
16 000	505.88	787	1174	40.1	.405
17 000	535.88	843	1270	39.9	.440
18 000	565.88	904	1369	39.8	.480
19 000	595.88	997	1581	38.7	.535
15 650	495.38	923	1484	38.4	.580
BEAM 311					
0	27.72	33	19	63.0	0.010
1000	57.72	51	39	56.9	.020
2000	87.72	75	62	54.7	.030
3000	117.72	105	78	57.4	.040
4000	147.72	134	101	57.0	.050
5000	177.72	168	125	57.3	.065
6000	207.72	206	157	56.6	.080
7000	237.72	255	242	51.4	.100
8000	267.72	310	305	50.4	.130
9000	297.72	359	401	47.2	.160
10 000	327.72	398	519	43.4	.190
11 000	357.72	461	601	43.4	.230
12 000	387.72	517	698	42.5	.260
13 000	417.72	566	778	42.1	.290
14 000	447.72	622	856	42.1	.330
15 000	477.72	674	938	41.8	.360
16 000	507.72	727	1028	41.4	.390
17 000	537.72	783	1113	41.3	.430
18 000	567.72	833	1195	41.1	.460
19 000	597.72	907	1344	40.3	.505
19 320	607.32	.....	.....	.....	.575
16 000	507.72	1059	2044	34.1	.590
BEAM 330					
0	26.09	26	21	55.7	0.010
1000	56.09	51	39	56.4	.020
2000	86.09	81	62	56.7	.030
3000	116.09	110	79	58.3	.040
4000	146.09	135	106	56.0	.050
5000	176.09	164	130	55.7	.065
6000	206.09	197	171	53.6	.080
7000	236.09	249	250	49.9	.100
8000	266.09	294	321	47.8	.125
9000	296.09	338	402	45.1	.150
10 000	326.09	401	503	44.4	.180
11 000	356.09	453	607	42.7	.210
12 000	386.09	491	691	41.5	.240
13 000	416.09	537	797	40.2	.270
14 000	446.09	588	875	40.2	.305
15 000	476.09	628	956	39.7	.330
16 000	506.09	676	1043	39.3	.360
17 000	536.09	729	1137	39.1	.400
18 000	566.09	777	1219	38.9	.420
19 000	596.09	817	1299	38.6	.455
20 000	626.09	878	1403	38.5	.490
20 760	648.89	.....	1513	.....	.520
21 000	656.09	958	1574	37.9	.555
18 350	576.59	896	1468	37.9	.590

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 331					
0	26.50	19	12	60.7	0.010
1000	56.50	48	27	63.9	.020
2000	86.50	74	53	58.4	.030
3000	116.50	105	68	60.6	.040
4000	146.50	137	91	60.2	.050
5000	176.50	166	116	58.9	.060
6000	206.50	203	154	56.8	.080
7000	236.50	249	214	53.8	.100
8000	266.50	299	275	52.1	.120
9000	296.50	353	357	49.8	.150
10 000	326.50	404	439	47.9	.170
11 000	356.50	459	521	46.8	.200
12 000	386.50	509	617	45.2	.230
13 050	418.00	567	718	44.1	.270
14 000	446.50	612	791	43.6	.295
15 000	476.50	663	877	43.1	.320
16 000	506.50	718	968	42.6	.360
17 000	536.50	773	1048	42.4	.390
18 000	566.50	818	1123	42.1	.415
19 000	596.50	868	1205	41.9	.450
20 000	626.50	917	1287	41.6	.480
21 000	656.50	980	1374	41.6	.510
21 580	673.90	.....	1432	.....	.530
19 000	596.50	1087	2306	32.1	.600
BEAM 332					
0	25.68	20	9	69.5	0.010
1000	55.68	53	39	57.4	.025
2000	85.68	81	56	59.1	.035
3000	115.68	113	82	57.9	.045
4000	145.68	142	103	58.0	.055
5000	175.68	177	132	57.4	.065
6000	205.68	217	174	55.4	.085
7000	235.68	271	224	54.7	.105
8000	265.68	332	292	53.2	.135
9000	295.68	375	381	49.6	.160
10 000	.....	.....	.....	.....	.....
11 000	355.68	478	564	45.9	.225
12 000	385.68	523	643	44.9	.255
13 000	415.68	573	728	44.0	.285
14 000	445.68	619	812	43.2	.315
15 000	475.68	669	908	42.4	.345
16 000	505.68	727	988	42.4	.375
17 000	535.68	766	1058	42.0	.405
18 000	565.68	824	1149	41.8	.445
19 000	595.68	877	1236	41.5	.475
20 000	625.68	940	1326	41.5	.505
21 000	655.68	1003	1422	41.4	.545
21 150	660.18	.....	1588	.....	.....
19 000	595.68	1127	2285	33.0	.625
BEAM 333					
0	24.44	28	24	53.5	0.010
1000	54.44	57	51	53.0	.020
2000	84.44	89	82	51.9	.030
2500	99.44	116	118	49.5	.040
2750	106.94	131	145	47.4	.045
3000	114.44	157	231	40.5	.065
3500	129.44	213	404	34.5	.115
4000	144.44	265	569	37.2	.160
4500	159.44	328	768	29.9	.210
5000	174.44	364	935	28.0	.235
5500	189.44	422	1104	27.7	.285
5800	198.44	.....	(1289)	.....	.325
5000	174.44	447	1382	24.4	.330

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 334					
0	24.23	27	22	55.5	0.010
2000	84.23	94	77	54.8	.035
2500	99.23	115	101	53.2	.050
2750	106.73	126	121	51.1	.055
3000	114.23	148	152	49.3	.065
3250	121.73	188	236	44.4	.090
3500	129.23	222	330	40.2	.110
4000	144.23	273	504	35.1	.155
4500	159.23	327	720	31.3	.200
5000	174.23	365	826	30.6	.250
5500	189.23	411	949	30.2	.290
6000	204.23	.....	(1253)	.....	.350
5000	174.23	472	1470	24.3	.365
BEAM 335					
0	24.85	22	20	52.5	0.010
1000	54.85	49	44	52.5	.020
2000	84.85	78	70	52.8	.035
2500	99.85	96	92	51.2	.040
2750	107.35	106	105	50.1	.045
3000	114.85	116	117	49.7	.050
3250	122.35	135	145	48.2	.065
3500	129.85	173	227	43.2	.080
4000	144.85	234	430	35.3	.125
4500	159.85	267	576	31.7	.170
5000	174.85	302	711	29.8	.210
5500	189.85	341	844	28.8	.255
6000	204.85	382	972	28.2	.295
6500	219.85	424	1150	26.9	.355
6610	223.15	.....	(1194)	.....	.370
BEAM 345					
0	25.06	21	21	50.4	0.010
1000	55.06	56	50	53.3	.020
2000	85.06	85	79	52.0	.030
2500	100.06	104	99	51.2	.040
3000	115.06	128	123	50.8	.055
3500	130.06	157	176	47.1	.070
4000	145.06	203	296	40.7	.090
4500	160.06	248	419	37.3	.125
5000	175.06	289	532	35.2	.155
6000	205.06	356	750	32.2	.215
7000	235.06	447	973	31.5	.275
8000	265.06	517	1185	30.4	.340
8500	280.06	566	1309	30.2	.360
9000	295.06	609	1460	29.5	.385
9420	307.66	.....	(1699)	.....	.435
8000	265.06	563	2084	24.2	.445

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 346					
0	24.85	27	27	49.3	0.010
1000	54.85	64	51	55.5	.020
2000	84.85	101	77	56.8	.035
2500	99.85	122	94	56.5	.040
3000	114.85	143	118	54.8	.055
3500	129.85	182	176	50.8	.070
4000	144.85	227	280	44.8	.100
4500	159.85	283	417	40.4	.135
5000	174.85	327	523	38.4	.165
6000	204.85	388	711	35.3	.220
7000	234.85	454	902	33.5	.285
8000	264.85	518	1073	32.5	.340
8500	279.85	560	1156	32.6	.370
9000	294.85	612	1328	31.5	.415
8200	270.85	635	1596	28.4	.435
BEAM 347					
0	24.85	23	19	54.6	0.010
1000	54.85	56	46	55.0	.020
2000	84.85	88	72	55.2	.030
2500	99.85	107	89	54.7	.040
3000	114.85	127	113	52.9	.050
3500	129.85	161	156	50.9	.060
4000	144.85	208	260	44.5	.085
4500	159.85	264	379	41.1	.120
5000	174.85	302	485	38.4	.155
6000	204.85	375	672	35.9	.215
7000	234.85	448	846	34.6	.275
8000	264.85	516	1019	33.6	.330
8500	279.85	555	1094	33.6	.360
9000	294.85	593	1185	33.4	.395
9250	302.35	.....	(1263)	.....	.425
7800	258.85	612	1643	27.1	.440
BEAM 357					
0	24.85	21	21	50.4	0.010
1000	54.85	51	44	53.4	.020
2000	84.85	82	70	53.6	.030
3000	114.85	117	97	54.5	.040
3500	129.85	138	130	51.5	.050
4000	144.85	167	173	49.2	.060
4500	159.85	203	238	46.1	.080
5000	174.85	243	335	42.0	.105
6000	204.85	310	492	38.7	.140
7000	234.85	377	638	37.2	.185
8000	264.85	437	781	35.9	.230
9000	294.85	500	923	35.1	.280
10 000	324.85	560	1063	34.5	.325
11 000	354.85	623	1200	34.2	.360
11 500	369.85	658	1267	34.2	.385
12 000	384.85	695	1338	34.2	.410
12 500	399.85	741	1408	34.5	.435
13 000	414.85	793	1557	33.7	.470
11 250	362.35	833	2012	29.3	.505

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 358					
0	25.06	21	19	52.5	0.010
1000	55.06	45	43	51.5	.020
2000	85.06	75	70	51.9	.030
3000	115.06	104	99	51.2	.040
3500	130.06	121	123	49.7	.050
4000	145.06	147	157	48.3	.060
4500	160.06	179	217	45.2	.080
5000	175.06	216	287	43.0	.105
6000	205.06	283	450	38.6	.150
7000	235.06	343	583	37.1	.195
8000	265.06	401	716	35.9	.245
9000	295.06	458	846	35.1	.295
10 000	325.06	518	968	34.9	.340
11 000	355.06	588	1097	34.9	.390
12 000	385.06	656	1241	34.6	.440
12 260	392.86	.....	(1296)	.....	.456
10 000	325.06	712	1831	28.0	.495
BEAM 359					
0	25.26	17	19	47.8	0.005
1000	55.26	44	48	47.8	.010
2000	85.26	74	70	51.5	.020
3000	115.26	102	99	50.8	.035
3500	130.26	123	120	50.7	.045
4000	145.26	150	156	49.1	.055
4500	160.26	180	207	46.5	.075
5000	175.26	222	313	41.5	.095
6000	205.26	287	487	37.0	.150
7000	235.26	306	660	31.7	.195
8000	265.26	375	805	31.8	.245
9000	295.26	435	944	31.5	.290
10 000	325.26	501	1073	31.8	.335
11 000	355.26	559	1214	31.5	.385
11 500	370.26	600	1291	31.8	.410
12 000	385.26	652	1350	32.6	.435
12 080	387.66	.....	(1379)	.....	.455
10 520	340.86	612	1265	32.6	.475
BEAM 369					
0	24.85	26	19	58.2	0.010
1000	54.85	58	39	59.5	.020
2000	84.85	90	65	58.0	.030
3000	114.85	127	103	55.5	.045
3500	129.85	155	137	53.1	.055
4000	144.85	182	174	51.1	.060
4500	159.85	213	224	48.8	.080
5000	174.85	253	282	47.2	.100
6000	204.85	321	421	43.3	.140
7000	234.85	385	549	41.2	.185
8000	264.85	449	679	39.8	.225
9000	294.85	514	809	38.9	.265
10 000	324.85	579	921	38.6	.305
11 000	354.85	641	1043	38.1	.350
12 000	384.85	715	1178	37.8	.395
13 000	414.85	805	1308	38.1	.440
14 000	444.85	862	1497	36.5	.500
12 300	393.85	889	1916	31.7	.535

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bc^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 370					
0	24.64	23	14	62.0	0.005
2000	84.64	86	63	57.7	.025
3000	114.64	124	104	54.5	.040
3500	129.64	152	138	52.2	.055
4000	144.64	180	183	49.7	.065
4500	159.64	213	232	47.9	.085
5000	174.64	247	299	45.3	.100
6000	204.64	312	432	41.9	.145
7000	234.64	377	568	39.9	.190
8000	264.64	440	697	38.7	.235
9000	294.64	495	834	37.3	.285
10 000	324.64	545	959	36.3	.325
11 000	354.64	608	1085	35.9	.370
12 000	384.64	685	1212	36.1	.415
13 000	414.64	794	1409	34.6	.470
13 400	426.64	.....	(1704)	.....	.515
12 100	387.64	890	1969	31.1	.535
BEAM 371					
0	24.64	21	22	48.5	0.010
1000	54.64	44	53	45.5	.020
2000	84.64	78	79	49.8	.030
3000	114.64	114	115	49.9	.045
3500	129.64	137	145	48.6	.055
4000	144.64	165	191	46.3	.070
5000	174.64	237	306	43.6	.110
6000	204.64	308	450	40.7	.150
7000	234.64	371	590	38.6	.195
8000	264.64	423	725	36.9	.240
9000	294.64	482	860	35.9	.280
10 000	324.64	570	991	36.5	.325
11 000	354.64	640	1120	36.4	.370
12 000	384.64	712	1229	36.7	.415
13 000	414.64	791	1356	36.9	.465
13 500	429.64	838	1461	36.4	.495
13 870	440.74	859	1527	36.0	.540
12 300	393.64	825	1446	36.3	.555
BEAM 381					
0	25.06	23	14	62.0	0.010
1000	55.06	55	39	58.0	.020
2000	85.06	82	62	57.3	.035
3000	115.06	118	89	57.0	.045
3500	130.06	149	111	55.6	.055
4000	145.06	166	145	53.3	.065
4500	160.06	197	186	51.4	.080
5000	175.06	228	239	48.8	.095
6000	205.06	292	342	46.0	.130
7000	235.06	354	462	43.4	.175
8000	265.06	418	583	41.7	.210
9000	295.06	480	689	41.1	.250
10 000	325.06	544	793	40.7	.290
11 000	355.06	611	909	40.2	.325
12 000	385.06	677	1003	40.3	.370
13 000	415.06	753	1115	40.3	.410
14 000	445.06	862	1234	41.1	.455
15 000	475.06	938	1409	40.0	.505
15 240	482.26	.....	(1631)	.....	.565
13 610	433.36	1064	1998	34.8	.580

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 382					
0	25.26	24	19	56.5	0.005
1000	55.26	58	41	58.5	.020
2000	85.26	91	67	57.6	.030
3000	115.26	119	97	54.9	.040
4000	145.26	168	156	52.0	.060
5000	175.26	227	244	48.2	.090
6000	205.26	292	354	45.2	.125
7000	235.26	355	480	42.5	.165
8000	265.26	417	602	40.9	.205
9000	295.26	478	704	40.4	.240
10 000	325.26	537	805	40.0	.280
11 000	355.26	598	935	39.0	.320
12 000	385.26	666	1041	39.0	.360
13 000	415.26	738	1164	38.8	.405
14 000	445.26	802	1274	38.6	.440
15 000	475.26	870	1392	38.5	.490
15 270	483.36	.....	(1468)	.....	.525
15 300	484.26	.....	(1621)	.....	.555
13 900	442.26	973	2005	32.7	.570
BEAM 383					
0	25.47	24	22	52.5	0.010
1000	55.47	55	48	53.3	.015
2000	85.47	82	70	53.6	.025
3000	115.47	115	101	53.2	.040
4000	145.47	158	154	50.6	.055
5000	175.47	210	234	47.3	.080
6000	205.47	269	337	44.5	.115
7000	235.47	324	462	41.3	.150
8000	265.47	379	566	40.1	.190
9000	295.47	434	694	38.5	.225
10 000	325.47	486	809	37.5	.265
11 000	355.47	541	921	37.0	.305
12 000	385.47	602	1034	36.8	.340
13 000	415.47	659	1139	36.7	.380
14 000	445.47	713	1236	36.6	.425
15 000	475.47	782	1362	36.5	.465
15 920	503.07	.....	(1539)	.....	.520
13 900	442.47	914	1662	35.5	.555
BEAM 393					
0	25.68	28	14	67.0	0.010
1000	55.68	50	36	58.4	.020
2000	85.68	86	60	59.0	.035
3000	115.68	118	85	58.2	.045
4000	145.68	156	116	57.2	.060
5000	175.68	207	178	53.8	.080
6000	205.68	265	250	50.5	.105
7000	235.68	335	354	48.7	.140
8000	265.68	382	459	45.4	.175
9000	295.68	434	542	44.4	.205
10 000	325.68	493	644	43.3	.245
11 000	355.68	549	745	42.4	.275
12 000	385.68	600	844	41.6	.310
13 000	415.68	658	933	41.3	.345
14 000	445.68	722	1038	41.0	.385
15 000	475.68	775	1132	40.7	.420
16 000	505.68	848	1224	41.0	.455
17 000	535.68	927	1326	41.1	.495
17 300	544.68	.....	1366	.....	.510
17 510	550.98	.....	1391	.....	.535
16 000	505.68	927	1321	41.3	.570

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 394					
0	25.26	26	14	65.0	0.005
1000	55.26	53	39	57.4	.015
2000	85.26	87	65	57.1	.030
3000	115.26	119	96	55.3	.040
4000	145.26	160	144	52.7	.055
5000	175.26	212	222	48.8	.080
6000	205.26	275	311	47.0	.105
7000	235.26	341	414	45.1	.145
8000	265.26	408	523	43.8	.175
9000	295.26	462	629	42.3	.210
10 000	325.26	518	733	41.4	.245
11 000	355.26	579	836	40.9	.285
12 000	385.26	627	915	40.7	.310
13 000	415.26	687	1015	40.4	.350
14 000	445.26	747	1103	40.4	.385
15 000	475.26	805	1207	40.0	.420
16 000	505.26	877	1308	40.1	.460
17 000	535.26	959	1402	40.6	.500
17 480	549.66	.....	1451	.....	.535
18 000	565.26	1043	1561	40.1	.565
18 240	572.46	.....	1626	.....	.585
15 600	493.26	1020	1494	40.6	.620
BEAM 395					
0	25.47	21	19	52.5	0.005
1000	55.47	50	38	57.0	.015
2000	85.47	84	63	57.1	.025
3000	115.47	113	87	56.5	.035
4000	145.47	148	118	55.7	.050
5000	175.47	195	186	51.2	.070
6000	205.47	253	274	48.1	.095
7000	235.47	312	386	44.7	.125
8000	265.47	364	516	41.3	.165
9000	295.47	420	602	41.1	.195
10 000	325.47	467	684	40.5	.225
11 000	355.47	525	776	40.3	.255
12 000	385.47	578	867	40.0	.295
13 000	415.47	632	961	39.7	.325
14 000	445.47	691	1039	40.0	.360
15 000	475.47	740	1140	39.4	.390
16 000	505.47	794	1239	39.1	.425
17 000	535.47	872	1344	39.3	.465
17 430	548.37	.....	1429	.....	.485
17 920	563.07	.....	1706	.....	.530
16 400	517.47	1058	2126	33.2	.585
BEAM 405					
0	25.47	21	14	59.7	0.005
1000	55.47	52	29	64.2	.010
2000	85.47	84	50	62.6	.020
3000	115.47	118	74	61.4	.035
4000	145.47	155	108	59.0	.045
5000	175.47	206	159	56.5	.065
6000	205.47	255	224	53.2	.090
7000	235.47	315	313	50.2	.120
8000	265.47	371	385	49.1	.145
9000	295.47	436	489	47.1	.165
10 000	325.47	486	566	46.2	.210
11 000	355.47	547	651	45.7	.245
12 000	385.47	611	737	45.3	.275
13 000	415.47	660	814	44.8	.305
14 000	445.47	721	886	44.9	.330
15 000	475.47	779	966	44.6	.360
16 000	505.47	832	1046	44.3	.390
17 000	535.47	904	1128	44.5	.425
18 000	565.47	975	1214	44.5	.465
19 000	595.47	1077	1380	43.8	.515
19 720	617.07	.....	1532	.....	.555
19 950	623.97	.....	1617	.....	.580
18 000	565.47	1302	2002	39.4	.605

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 406					
0	25.88	24	15	61.5	0.010
1000	55.88	50	39	56.4	.020
2000	85.88	79	63	55.7	.030
3000	115.88	109	85	56.1	.040
4000	145.88	149	126	54.1	.045
5000	175.88	197	188	51.2	.075
6000	205.88	248	267	48.1	.100
7000	235.88	303	359	45.8	.130
8000	265.88	374	458	44.9	.155
9000	295.88	409	532	43.5	.190
10 000	325.88	466	622	42.9	.220
11 000	355.88	521	708	42.4	.250
12 000	385.88	572	798	41.7	.280
13 000	415.88	622	879	41.4	.315
14 000	445.88	686	966	41.5	.345
15 000	475.88	735	1044	41.3	.375
16 000	505.88	793	1132	41.2	.405
17 000	535.88	856	1221	41.2	.440
18 000	565.88	911	1302	41.1	.480
19 000	595.88	974	1393	41.1	.510
19 800	619.88	1125	1783	38.7	.585
18 800	574.88	1228	2328	34.5	.635
BEAM 407					
0	25.68	24	19	56.0	0.010
1000	55.68	48	36	57.3	.020
2000	85.68	75	58	56.3	.030
3000	115.68	107	92	53.8	.045
4000	145.68	151	133	53.2	.060
5000	175.68	195	176	52.5	.075
6000	205.68	246	248	49.8	.100
7000	235.68	298	323	48.0	.130
8000	265.68	351	405	46.4	.155
9000	295.68	403	499	44.7	.185
10 000	325.68	455	586	43.7	.220
11 000	355.68	513	684	42.8	.250
12 000	385.68	563	768	42.3	.280
13 000	415.68	619	853	42.0	.310
14 000	445.68	683	937	42.2	.345
15 000	475.68	731	1014	41.9	.375
16 000	505.68	793	1097	42.0	.405
17 000	535.68	852	1192	41.7	.445
18 000	565.68	912	1277	41.7	.480
19 000	595.68	979	1366	41.8	.515
20 000	625.68	1077	1520	41.5	.565
20 280	634.08	.....	1572	.....	.580
20 410	637.98	.....	1662	.....	.600
20 450	639.18	.....	1788	.....	.630
18 400	577.68	1250	2169	36.6	.655
BEAM 336					
0	24.85	19	17	52.5	0.005
1000	54.85	55	39	58.4	.015
2000	84.85	81	67	54.9	.025
2500	99.85	96	80	54.5	.035
3000	114.85	112	99	53.0	.040
3500	129.85	136	133	50.6	.050
4000	144.85	174	217	44.4	.065
4500	159.85	217	369	37.1	.105
5000	174.85	278	610	31.3	.165
5500	189.85	329	809	28.9	.205
6000	204.85	371	990	27.3	.255
6500	219.85	404	1116	26.6	.295
7000	234.85	439	1256	25.9	.335
7350	245.35	.....	1357	.....	.365
5700	195.85	444	1783	20.0	.375

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 337					
0	24.85	17	21	44.6	0.010
1000	54.85	48	44	52.0	.020
2000	84.85	66	63	51.3	.030
3000	114.85	112	115	49.4	.050
3500	129.85	138	156	46.9	.060
4000	144.85	172	236	42.2	.080
4500	159.85	237	472	33.5	.130
5000	174.85	282	639	30.6	.170
5500	189.85	319	815	28.1	.215
6000	204.85	359	993	26.5	.270
6500	219.85	398	1162	25.5	.310
6740	227.05	.....	1241	.....	.340
5600	192.85	491	1154	29.9	.340
BEAM 338					
0	24.64	21	19	52.5	0.010
1000	54.64	51	43	54.1	.025
2000	84.64	75	63	54.3	.035
3000	114.64	115	109	51.4	.055
3500	129.64	142	140	50.4	.060
4000	144.64	182	217	45.6	.085
4500	159.64	235	373	38.6	.120
5000	174.64	286	566	33.5	.170
5500	189.64	337	797	29.7	.225
.....	.....	.....	.....	.....	.....
5000	174.64	411	1684	19.6	.330
BEAM 348					
0	25.26	23	15	60.4	0.010
1000	55.26	53	36	58.0	.025
2000	85.26	77	56	57.8	.035
3000	115.26	113	85	57.0	.050
3500	130.26	126	103	55.1	.055
4000	145.26	146	127	53.4	.060
4500	160.26	167	168	49.8	.070
5000	175.26	209	253	45.3	.100
5500	190.26	257	362	41.5	.120
6000	205.26	293	472	38.3	.150
7000	235.26	357	656	35.2	.210
8000	265.26	421	865	32.8	.270
9000	295.26	481	1073	31.0	.330
9370	306.36	.....	1154	.....	.355
9620	313.86	.....	1338	.....	.390
8000	265.26	534	1726	23.7	.395

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 349					
0	25.47	13	15	47.2	0.010
1000	55.47	42	39	51.9	.020
2000	85.47	64	60	51.7	.040
3000	115.47	93	84	52.5	.050
4000	145.47	117	111	51.4	.065
4500	160.47	145	149	49.3	.080
5000	175.47	171	207	45.2	.100
5500	190.47	217	321	40.3	.120
6000	205.47	257	456	36.0	.150
7000	235.47	321	706	31.3	.220
8000	265.47	380	913	29.4	.280
9000	295.47	433	1087	28.5	.330
9500	310.47	464	1197	27.9	.360
10 000	325.47	489	1294	27.4	.390
10 500	340.47	516	1378	27.2	.415
11 000	355.47	551	1467	27.3	.440
11 050	356.97	.....	1516	.....	.465
9300	304.47	548	1981	21.7	.475
BEAM 350					
0	25.06	19	21	47.5	0.005
1000	55.06	43	46	48.6	.020
2000	85.06	70	68	49.6	.030
3000	115.06	102	96	51.5	.040
4000	145.06	133	130	50.6	.050
4500	160.06	160	169	48.7	.060
5000	175.06	198	248	44.4	.080
5500	190.06	244	390	38.5	.115
6000	205.06	289	533	35.2	.150
7000	235.06	360	754	32.3	.210
8000	265.06	418	945	30.7	.265
8800	289.06	.....	1250	.....	.345
7500	250.06	498	1597	23.8	.355
BEAM 360					
0	25.26	23	17	57.5	0.010
1000	55.26	56	43	56.5	.015
2000	85.26	84	65	56.5	.025
3000	115.26	107	87	55.1	.035
4000	145.26	135	111	54.9	.045
4500	160.26	158	130	54.9	.050
5000	175.26	181	162	52.8	.060
5500	190.26	206	222	48.2	.080
6000	205.26	246	330	42.7	.100
7000	235.26	309	508	37.8	.150
8000	265.26	358	643	35.8	.190
9000	295.26	409	786	34.2	.230
10 000	325.26	453	938	32.6	.275
11 000	355.26	508	1068	32.2	.320
12 000	385.26	556	1200	31.7	.360
12 850	410.76	.....	1362	.....	.400
10 700	346.26	626	1921	24.6	.430

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 361					
0	25.47	17	14	54.1	0.010
1000	55.47	45	34	55.9	.015
2000	85.47	68	53	56.2	.030
3000	115.47	92	77	54.6	.035
4000	145.47	119	103	53.6	.050
4500	160.47	134	123	52.1	.055
5000	175.47	152	154	49.7	.065
5500	190.47	184	209	46.8	.075
6000	205.47	222	309	41.8	.105
7000	235.47	282	486	36.8	.150
8000	265.47	338	636	34.7	.195
9000	295.47	384	769	33.3	.235
10 000	325.47	429	904	32.2	.275
11 000	355.47	478	1039	31.5	.320
12 000	385.47	521	1188	30.5	.360
12 450	398.97	.....	1309	.....	.390
11 500	370.47	537	1484	36.6	.395
BEAM 362					
0	25.06	17	15	52.5	0.010
1000	55.06	48	39	55.4	.015
2000	85.06	75	56	57.1	.025
3000	115.06	106	85	55.4	.040
4000	145.06	138	118	53.9	.050
4500	160.06	157	144	52.2	.060
5000	175.06	183	190	49.0	.070
5500	190.06	215	268	44.5	.090
6000	205.06	257	362	41.5	.110
7000	235.06	320	545	37.0	.160
8000	265.06	381	716	34.7	.205
9000	295.06	449	906	33.1	.260
10 000	325.06	484	998	32.7	.290
11 000	355.06	545	1145	32.2	.335
12 000	385.06	597	1282	31.8	.380
12 960	413.86	.....	1468	.....	.430
11 100	358.06	651	1896	25.5	.440
BEAM 372					
0	25.68	21	19	52.5	0.010
1000	55.68	53	41	56.2	.020
2000	85.68	82	65	55.9	.030
3000	115.68	111	89	55.5	.040
4000	145.68	143	125	53.4	.055
5000	175.68	190	195	49.4	.075
6000	205.68	246	299	45.2	.110
7000	235.68	304	429	41.4	.145
8000	265.68	359	582	39.0	.190
9000	295.68	413	668	38.2	.230
10 000	325.68	460	786	36.9	.265
11 000	355.68	514	901	36.3	.310
12 000	385.68	561	1026	35.4	.345
13 000	415.68	618	1138	35.2	.390
14 000	445.68	667	1248	34.8	.430
14 650	465.18	.....	1325	.....	.455
14 870	471.78	.....	1385	.....	.470
12 850	411.18	752	1921	28.2	.505

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 373					
0	25.47	21	17	55.1	0.010
1000	55.47	50	34	59.6	.020
2000	85.47	81	58	58.3	.035
3000	115.47	108	79	57.8	.055
4000	145.47	139	106	56.8	.075
5000	175.47	188	161	53.9	.100
6000	205.47	253	284	47.1	.140
7000	235.47	310	417	42.7	.175
8000	265.47	366	559	39.6	.220
9000	295.47	417	684	37.9	.255
10 000	325.47	471	807	36.8	.....
11 000	355.47	523	918	36.3	.340
12 000	385.47	574	1027	35.9	.380
13 000	415.47	620	1137	35.3	.420
14 000	445.47	676	1241	35.3	.455
15 000	475.47	725	1361	34.8	.495
15 150	479.97	.....	1376	.....	.505
12 850	410.97	740	1916	27.9	.525
BEAM 374					
0	25.68	21	19	52.5	0.010
1000	55.68	49	44	52.5	.....
2000	85.68	77	65	54.3	.020
3000	115.68	107	92	53.8	.030
4000	145.68	139	128	52.1	.040
5000	175.68	188	210	47.2	.060
6000	205.68	250	325	43.5	.095
7000	235.68	313	470	40.0	.140
8000	265.68	364	597	37.9	.175
9000	295.68	419	728	36.5	.220
10 000	325.68	473	856	35.6	.260
11 000	355.68	523	980	34.8	.300
12 000	385.68	573	1106	34.1	.340
13 000	415.68	631	1238	33.7	.380
14 000	445.68	690	1380	33.3	.430
14 550	462.18	.....	1458	.....	.455
12 750	408.18	742	1858	28.5	.475
BEAM 384					
0	25.26	21	14	59.7	0.010
1000	55.26	47	32	59.5	.020
2000	85.26	75	58	56.3	.030
3000	115.26	103	84	55.2	.040
4000	145.26	130	108	54.6	.050
5000	175.26	170	159	51.7	.070
6000	205.26	220	236	48.2	.090
7000	235.26	276	357	43.6	.120
8000	265.26	332	489	40.4	.155
9000	295.26	380	610	38.3	.195
10 000	325.26	423	716	37.1	.230
11 000	355.26	477	829	36.5	.270
12 000	385.26	521	935	35.8	.300
13 000	415.26	565	1038	35.3	.335
14 000	445.26	610	1137	34.9	.370
15 000	475.26	661	1231	34.9	.405
16 000	505.26	710	1345	34.5	.445
16 660	525.06	.....	1455	.....	.480
16 700	526.06	.....	1480	.....	.490
16 750	527.76	.....	1540	.....	.500
16 840	530.46	.....	1653	.....	.520
14 300	454.26	815	2089	28.1	.550

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 385					
0	25.68	21	15	58.1	0.010
1000	55.68	48	36	57.3	.020
2000	85.68	77	58	56.9	.030
3000	115.68	103	80	56.3	.040
4000	145.68	132	111	54.3	.050
5000	175.68	176	159	52.5	.070
6000	205.68	223	231	49.1	.090
7000	235.68	275	345	44.4	.125
8000	265.68	333	480	40.9	.160
9000	295.68	386	603	39.1	.200
10 000	325.68	436	721	37.7	.230
11 000	355.68	485	831	36.8	.270
12 000	385.68	537	952	36.0	.300
13 000	415.68	583	1053	35.6	.340
14 000	445.68	634	1169	35.2	.370
15 000	475.68	676	1270	34.8	.410
16 000	505.68	746	1415	34.5	.450
16 120	509.28	.....	1441	.....	.460
16 720	527.28	.....	1559	.....	.485
14 300	454.68	849	2186	28.0	.525
BEAM 386					
0	25.47	19	17	52.5	0.005
1000	55.47	48	39	55.4	.015
2000	85.47	75	62	54.7	.025
3000	115.47	107	84	55.9	.035
4000	145.47	138	113	54.9	.050
5000	175.47	172	157	52.3	.065
6000	205.47	228	238	49.0	.085
7000	235.47	306	359	46.0	.130
8000	265.47	351	467	43.0	.165
9000	295.47	402	585	40.8	.205
10 000	325.47	450	692	39.9	.240
11 000	355.47	506	798	38.8	.275
12 000	385.47	552	911	37.7	.315
13 000	415.47	608	1033	37.1	.350
14 000	445.47	653	1125	36.7	.380
15 000	475.47	709	1241	36.4	.415
16 000	505.47	775	1391	35.8	.465
14 000	445.47	822	1974	29.4	.510
BEAM 396					
0	25.47	19	21	47.5	0.010
1000	55.47	45	41	52.5	.020
2000	85.47	68	60	53.3	.030
3000	115.47	98	82	54.4	.040
4000	145.47	128	104	55.1	.050
5000	175.47	160	138	53.7	.065
6000	205.47	208	195	51.6	.080
7000	235.47	250	273	47.8	.105
8000	265.47	308	376	45.0	.135
9000	295.47	358	475	42.9	.170
10 000	325.47	401	574	41.1	.195
11 000	355.47	446	670	39.9	.230
12 000	385.47	486	756	39.2	.255
13 000	415.47	534	841	38.8	.295
14 000	445.47	578	920	38.6	.320
15 100	478.47	627	1019	38.1	.355
16 000	505.47	666	1091	37.9	.380
17 000	535.47	716	1186	37.6	.410
18 000	565.47	764	1294	37.3	.440
18 630	584.37	807	1359	37.3	.475
19 000	595.47	834	1443	36.6	.485
19 650	614.97	.....	1602	.....	.535
17 000	535.47	911	2128	30.0	.550

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 397					
0	25.47	21	15	58.1	0.010
1000	55.47	52	31	62.7	.020
2000	85.47	78	50	61.1	.030
3000	115.47	106	70	60.2	.040
4000	145.47	132	91	59.2	.050
5000	175.47	168	120	58.4	.065
6000	205.47	207	169	55.0	.080
7000	235.47	257	258	49.9	.105
8000	265.47	304	371	45.0	.135
9000	295.47	349	477	42.3	.165
10 000	325.47	398	574	40.9	.195
11 000	355.47	441	667	39.8	.225
12 000	385.47	484	747	39.3	.255
13 000	415.47	528	836	38.7	.290
14 000	445.47	569	930	38.0	.320
15 000	475.47	612	1019	37.5	.350
16 000	505.47	656	1113	37.1	.380
17 100	538.47	712	1231	36.6	.420
18 000	565.47	771	1340	36.5	.455
19 000	595.47	828	1477	35.9	.495
19 960	624.27	.....	1718	.....	.555
19 880	621.87	.....	1900	.....	.570
17 300	544.47	962	2313	29.4	.595
BEAM 398					
0	26.09	21	14	59.7	0.010
1000	56.09	48	39	55.4	.020
2000	86.09	77	60	56.2	.030
3000	116.09	103	74	58.1	.040
4000	146.09	133	99	57.2	.055
5000	176.09	169	137	55.3	.070
6000	206.09	213	195	52.3	.090
7000	236.09	267	296	47.4	.120
8000	266.09	321	376	46.0	.150
9000	296.09	369	468	44.1	.185
10 000	326.09	415	564	42.4	.215
11 000	356.09	461	667	40.9	.250
12 000	386.09	507	747	40.4	.280
13 000	416.09	554	839	39.8	.310
14 000	446.09	605	932	39.4	.345
15 000	476.09	647	1015	38.9	.370
16 000	506.09	696	1118	38.4	.400
17 000	536.09	747	1193	38.5	.430
18 000	566.09	883	1294	38.3	.470
18 930	593.99	.....	1458	.....	.510
19 000	596.09	898	1538	36.9	.525
19 100	599.09	.....	1655	.....	.550
16 900	533.09	952	2089	31.3	.565
BEAM 408					
0	26.09	23	17	57.5	0.005
1000	56.09	52	32	62.0	.015
2000	86.09	76	53	59.1	.025
3000	116.09	106	72	59.5	.035
4000	146.09	131	94	58.3	.045
5000	176.09	161	120	57.3	.055
6000	206.09	204	174	54.0	.070
7000	236.09	229	250	49.9	.090
8000	266.09	302	338	47.2	.120
9000	296.09	354	426	45.4	.145
10 000	326.09	400	513	43.8	.175
11 000	356.09	451	600	42.9	.205
12 000	386.09	487	674	41.9	.235
13 000	416.09	536	747	41.8	.260
14 000	446.09	570	805	41.4	.285
15 000	476.09	617	894	40.9	.315
16 000	506.09	667	974	40.6	.345
17 000	536.09	707	1050	40.2	.375
18 000	566.09	753	1137	39.8	.405
19 000	596.09	810	1215	40.0	.435
20 000	626.09	857	1297	39.8	.465
21 000	656.09	915	1385	39.8	.500
21 840	681.29	.....	1462	.....	.525
22 000	686.09	.....	1504	.....	.540
20 000	626.09	978	2135	31.4	.570

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 409					
0	26.29	23	15	60.4	0.010
1000	56.29	47	36	56.7	.015
2000	86.29	71	55	56.5	.025
3000	116.29	95	74	56.3	.035
4000	146.29	124	96	56.4	.045
5000	176.29	156	120	56.5	.055
6000	206.29	196	158	53.9	.075
7000	236.29	248	232	51.7	.100
8000	266.29	295	311	48.7	.125
9000	296.29	340	400	45.9	.150
10 000	326.29	388	492	44.1	.180
11 000	356.29	434	576	42.9	.205
12 000	386.29	476	662	41.8	.240
13 000	416.29	518	739	41.2	.270
14 000	446.29	563	821	40.7	.290
15 000	476.29	608	892	40.5	.320
16 000	506.29	656	973	40.2	.350
17 000	536.29	702	1051	40.0	.380
18 000	566.29	749	1127	39.9	.405
19 000	596.29	794	1200	39.8	.440
20 000	626.29	858	1301	39.7	.470
21 000	656.29	914	1397	39.5	.500
21 300	665.29	.....	1436	.....	.520
22 000	686.29	1004	1596	38.6	.550
22 350	696.79	.....	1826	.....	.595
20 000	626.29	1114	2388	31.8	.625
BEAM 410					
0	25.47	23	15	60.4	0.010
1000	55.47	56	38	59.4	.020
2000	85.47	82	53	60.7	.030
3000	115.47	108	77	58.4	.040
4000	145.47	133	99	57.2	.050
5000	175.47	167	133	55.7	.065
6000	205.47	210	183	53.4	.080
7000	235.47	260	256	50.4	.110
8000	265.47	315	350	47.4	.140
9000	295.47	367	446	45.1	.170
10 000	325.47	411	532	43.6	.195
11 000	355.47	457	615	42.6	.220
12 000	385.47	499	699	41.6	.250
13 000	415.47	546	774	41.4	.280
14 000	445.47	590	855	40.8	.305
15 000	475.47	638	939	40.4	.340
16 000	505.47	682	1017	40.1	.365
17 000	535.47	725	1094	39.9	.390
18 000	565.47	772	1173	39.7	.420
19 000	595.47	838	1258	40.0	.460
20 000	625.47	898	1349	40.0	.490
21 000	655.47	961	1472	39.5	.525
21 640	674.67	.....	1568	.....	.560
21 690	676.17	.....	1610	.....	.575
19 800	619.47	1080	2163	33.3	.600
BEAM 339					
0	24.85	17	15	52.5	0.010
1000	54.85	43	38	53.1	.020
2000	84.85	68	60	53.3	.030
2500	99.85	83	72	53.5	.035
3000	114.85	98	91	52.0	.040
3500	129.85	118	113	51.0	.050
4000	144.85	148	173	46.1	.060
4500	159.85	216	347	38.4	.110
5000	174.85	261	526	33.2	.155
5500	189.85	309	720	30.1	.200
6000	204.85	349	892	28.1	.245
6500	219.85	396	1127	26.0	.280
5850	200.35	.....	2037	.....	.390

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 340					
0	24.85	21	14	59.7	0.010
1000	54.85	45	39	53.7	.020
2000	84.85	72	62	53.6	.030
2500	99.85	85	77	53.5	.040
3000	114.85	102	92	52.5	.045
3500	129.85	120	116	50.8	.050
4000	144.85	145	161	47.4	.650
4500	159.85	199	325	38.0	.105
5000	174.85	257	585	30.5	.165
5500	189.85	296	749	28.3	.210
6000	204.85	329	884	27.1	.250
6500	219.85	361	1029	25.9	.290
5500	189.85	378	1600	19.1	.335
BEAM 341					
0	24.85	17	15	52.5	0.005
1000	54.85	43	38	53.1	.015
2000	84.85	67	65	50.6	.025
2500	99.85	83	75	52.5	.035
3000	114.85	99	92	51.7	.040
3500	129.85	112	109	50.3	.045
4000	144.85	135	142	48.2	.053
4500	159.85	191	268	41.6	.090
5000	174.85	265	585	31.1	.155
5500	189.85	305	771	28.3	.205
6000	204.85	344	949	26.6	.250
6500	219.85	384	1144	25.2	.300
6680	225.25	.....	(1212)	.....	.320
5250	182.35	338	1080	23.8	.330
BEAM 351					
0	25.06	19	14	57.1	0.010
1000	55.06	47	31	60.2	.020
2000	85.06	71	55	56.5	.030
3000	115.06	100	77	56.5	.040
3500	130.06	116	89	56.6	.050
4000	145.06	132	104	55.9	.055
4500	160.06	157	144	52.2	.065
5000	175.06	197	213	47.8	.085
5500	190.06	236	337	41.1	.110
6000	205.06	282	479	37.1	.150
7000	235.06	349	682	33.8	.205
8000	265.06	404	872	31.6	.260
9000	295.06	461	1046	30.6	.315
10 000	325.06	519	1241	29.5	.370
7850	260.56	517	1759	22.7	.395

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 352					
0	25.47	19	14	44.4	0.010
1000	55.47	45	41	52.5	.020
2000	85.47	70	65	51.8	.030
3000	115.47	101	91	52.5	.040
3500	130.47	115	106	52.0	.045
4000	145.47	133	128	51.0	.050
4500	160.47	158	171	48.1	.065
5000	175.47	197	256	43.4	.085
6000	205.47	268	458	36.9	.140
7000	235.47	339	663	33.8	.190
8000	265.47	388	843	31.5	.245
9000	295.47	443	1003	30.6	.300
10 000	325.47	497	1164	29.9	.345
10 800	334.47	.....	1220	.....	.380
8450	278.97	451	1080	29.4	.430
BEAM 353					
0	25.06	19	17	52.5	0.010
1000	55.06	47	36	56.7	.015
2000	85.06	77	60	56.2	.025
3000	115.06	103	80	56.3	.035
3500	130.06	120	96	55.5	.040
4000	145.06	133	111	54.5	.050
4500	160.06	157	147	51.7	.055
5000	175.06	188	207	47.6	.075
6000	205.06	265	414	39.0	.130
7000	235.06	327	607	35.0	.185
8000	265.06	387	788	32.9	.245
9000	295.06	438	950	31.6	.305
9830	319.96	.....	1078	.....	.360
8300	274.06	436	1002	30.3	.370
BEAM 363					
0	25.47	19	17	52.5	0.010
1000	55.47	42	39	51.9	.015
2000	85.47	61	60	50.4	.025
3000	115.47	90	77	54.0	.035
4000	145.47	119	106	52.9	.050
5000	175.47	153	147	51.0	.065
6000	205.47	209	256	45.0	.090
7000	235.47	269	426	38.7	.135
8000	265.47	330	595	35.7	.175
9000	295.47	387	747	34.1	.225
10 000	325.47	432	884	32.8	.265
11 000	355.47	484	1024	32.1	.310
12 000	385.47	530	1149	31.6	.350
13 000	415.47	583	1299	31.0	.395
13 530	431.37	.....	1429	.....	.445
11 130	359.37	613	1967	23.8	.450

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 364					
0	25.06	17	14	54.1	0.010
1000	55.06	43	36	54.4	.020
2000	85.06	68	53	55.3	.030
3000	115.06	94	80	53.9	.040
4000	145.06	127	113	52.9	.050
5000	175.06	160	162	49.7	.065
6000	205.06	210	267	44.0	.090
7000	235.06	270	455	37.3	.135
8000	265.06	321	629	33.8	.175
9000	295.06	377	801	32.0	.225
10 000	325.06	420	950	30.7	.270
11 000	355.06	466	1094	29.9	.315
12 000	385.06	513	1229	29.5	.350
13 000	415.06	569	1448	28.2	.410
13 100	418.06	.....	1543	.....	.430
11 400	367.06	571	1925	22.9	.445
BEAM 365					
0	25.26	19	12	60.7	0.010
1000	55.26	45	34	56.9	.020
2000	85.26	66	55	54.6	.030
3000	115.26	96	77	55.4	.040
4000	145.26	119	101	54.1	.050
5000	175.26	157	150	51.2	.065
6000	205.26	215	267	44.6	.100
7000	235.26	282	438	39.2	.145
8000	265.26	337	576	36.9	.180
9000	295.26	387	718	35.0	.230
10 000	325.26	437	843	34.1	.270
11 000	355.26	481	956	33.5	.310
12 000	385.26	532	1080	33.0	.350
13 000	415.26	588	1239	32.2	.400
10 600	343.26	592	1812	24.6	.425
BEAM 375					
0	25.06	19	12	60.7	0.005
1000	55.06	45	32	58.4	.015
2000	85.06	69	53	56.6	.025
3000	115.06	92	77	54.6	.040
4000	145.06	122	106	53.6	.050
5000	175.06	157	147	51.7	.065
6000	205.06	204	220	48.1	.090
7000	235.06	267	362	42.5	.130
8000	265.06	324	511	38.8	.165
9000	295.06	376	650	36.7	.205
10 000	325.06	422	776	35.2	.240
11 000	355.06	478	899	34.7	.285
12 000	385.06	523	1024	33.8	.320
13 000	415.06	573	1152	33.2	.365
14 000	445.06	625	1270	33.0	.405
15 000	475.06	683	1415	32.6	.445
15 780	498.46	.....	1579	.....	.500
12 900	412.06	644	1362	32.1	.510

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 376					
0	24.85	16	10	62.0	0.010
1000	54.85	43	36	54.4	.020
2000	84.85	68	56	54.9	.030
3000	114.85	94	79	54.2	.040
4000	144.85	125	109	53.4	.055
5000	174.85	165	164	50.2	.070
6000	204.85	216	243	47.1	.100
7000	234.85	273	368	42.6	.135
8000	264.85	329	518	38.9	.175
9000	294.85	372	643	36.6	.215
10 000	324.85	425	762	35.8	.255
11 000	354.85	470	884	34.7	.295
12 000	384.85	511	983	34.2	.330
13 000	414.85	560	1101	33.7	.375
14 000	444.85	599	1205	33.2	.410
14 990	474.55	.....	1328	.....	.470
12 850	410.35	593	1193	33.2	.475
BEAM 377					
0	24.85	17	22	43.5	0.010
1000	54.85	45	43	51.4	.020
2000	84.85	69	68	50.3	.025
3000	114.85	96	91	51.4	.035
4000	144.85	123	116	51.5	.050
5000	174.85	156	161	49.2	.065
6000	204.85	205	239	46.2	.090
7000	234.85	263	373	41.3	.120
8000	264.85	322	520	38.3	.165
9000	294.85	374	643	36.8	.205
10 000	324.85	428	774	35.6	.245
11 000	354.85	478	899	34.7	.285
12 000	384.85	528	1027	33.9	.325
13 000	414.85	571	1142	33.3	.360
14 000	444.85	627	1267	33.1	.405
15 000	474.85	693	1448	32.4	.455
15 360	485.65	.....	1543	.....	.490
12 650	404.35	637	1357	31.9	.500
BEAM 387					
0	25.47	19	17	52.5	0.010
1000	55.47	45	36	55.6	.020
2000	85.47	73	56	56.7	.030
3000	115.47	101	77	56.7	.040
4000	145.47	132	99	57.1	.050
5000	175.47	169	138	55.1	.065
6000	205.47	219	195	52.9	.085
7000	235.47	278	285	49.4	.115
8000	265.47	338	390	46.5	.145
9000	295.47	398	521	43.3	.190
10 000	325.47	450	612	42.4	.225
11 000	355.47	499	711	41.3	.255
12 000	385.47	554	817	40.4	.295
13 000	415.47	604	920	39.6	.325
14 000	445.47	657	1026	39.0	.365
15 000	475.47	701	1126	38.4	.400
16 000	505.47	788	1249	38.7	.440
16 880	531.87	.....	1607	.....	.525
14 500	460.47	910	2140	29.8	.545

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 388					
0	25.26	17	15	52.5	0.010
1000	55.26	42	36	53.8	.020
2000	85.26	66	55	54.6	.030
3000	115.26	95	74	56.3	.040
4000	145.26	120	99	54.8	.050
5000	175.26	157	140	52.8	.065
6000	205.26	200	217	47.9	.090
7000	235.26	255	325	44.0	.120
8000	265.26	311	453	40.6	.160
9000	295.26	359	585	38.0	.190
10 000	325.26	410	704	36.8	.225
11 000	355.26	450	832	35.1	.265
12 000	385.26	497	930	34.8	.295
13 000	415.26	542	1031	34.4	.330
14 000	445.26	590	1137	34.2	.365
15 000	475.26	630	1232	33.8	.395
16 000	505.26	680	1340	33.7	.435
17 000	535.26	.....	1516	.....	.485
15 000	475.26	758	1930	28.2	.500
BEAM 389					
0	25.47	17	15	52.5	0.005
1000	55.47	47	39	54.8	.015
2000	85.47	69	60	53.7	.025
3000	115.47	101	82	55.2	.035
4000	145.47	130	106	55.0	.050
5000	175.47	164	138	54.3	.065
6000	205.47	216	210	50.7	.085
7000	235.47	273	299	47.7	.115
8000	265.47	331	412	44.6	.155
9000	295.47	383	528	42.0	.185
10 000	325.47	432	650	39.9	.225
11 000	355.47	484	762	38.9	.260
12 000	385.47	532	863	38.1	.295
13 000	415.47	580	966	37.5	.325
14 000	445.47	629	1072	37.0	.365
15 000	475.47	680	1171	36.8	.395
16 000	505.47	731	1272	36.5	.435
16 980	534.87	.....	1463	.....	.485
14 350	455.97	806	2046	28.2	.510
BEAM 399					
0	25.47	17	15	52.5	0.005
1000	55.47	47	34	58.0	.015
2000	85.47	69	53	56.6	.025
3000	115.47	98	74	56.9	.035
4000	145.47	127	97	56.7	.045
5000	175.47	159	126	55.8	.060
6000	205.47	198	173	53.3	.075
7000	235.47	246	244	50.3	.100
8000	265.47	297	335	47.0	.125
9000	295.47	349	446	43.9	.160
10 000	325.47	399	544	42.3	.190
11 000	355.47	444	634	41.2	.220
12 000	385.47	492	723	40.5	.245
13 000	415.47	540	814	39.9	.275
14 000	445.47	587	896	39.6	.310
15 000	475.47	630	979	39.2	.335
16 000	505.47	678	1068	38.8	.365
17 000	535.47	726	1154	38.6	.395
18 000	565.47	778	1250	38.4	.430
19 000	595.47	828	1338	38.2	.460
19 650	614.97	.....	1496	.....	.495
17 400	547.47	940	2048	31.4	.525

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 400					
0	25.68	17	14	54.1	0.005
1000	55.68	42	32	56.6	.015
2000	85.68	62	51	54.7	.025
3000	115.68	90	72	55.6	.035
4000	145.68	114	92	55.4	.045
5000	175.68	147	126	53.8	.060
6000	205.68	187	174	51.8	.075
7000	235.68	223	239	48.3	.100
8000	265.68	277	337	45.1	.125
9000	295.68	318	429	42.4	.155
10 000	325.68	361	533	40.4	.185
11 000	355.68	401	629	39.0	.215
12 000	385.68	441	720	38.0	.245
13 000	415.68	485	809	37.5	.270
14 000	445.68	527	894	37.1	.305
15 000	475.68	569	974	36.9	.330
16 000	505.68	606	1056	36.5	.360
17 000	535.68	648	1140	36.3	.390
18 000	565.68	694	1229	36.1	.420
19 000	595.68	741	1313	36.1	.455
20 000	625.68	.....	1415	.....	.495
17 500	550.68	828	2041	28.9	.530
BEAM 401					
0	25.47	17	19	46.9	0.010
1000	55.47	43	38	53.1	.015
2000	85.47	64	58	52.5	.025
3000	115.47	94	79	54.2	.035
4000	145.47	122	102	54.5	.045
5000	175.47	157	140	52.8	.060
6000	205.47	196	198	49.7	.080
7000	235.47	243	273	47.1	.105
8000	265.47	293	371	44.1	.135
9000	295.47	347	475	42.2	.165
10 000	325.47	391	585	40.0	.195
11 000	355.47	437	687	38.9	.225
12 000	385.47	474	769	38.1	.250
13 000	415.47	520	860	37.7	.285
14 000	445.47	560	945	37.2	.310
15 000	475.47	602	1031	36.8	.335
16 000	505.47	649	1113	36.8	.370
17 000	535.47	689	1202	36.5	.400
18 000	565.47	740	1290	36.4	.430
19 000	595.47	802	1456	35.5	.475
19 380	606.87	.....	1578	.....	.505
17 450	548.97	842	2055	29.1	.515
BEAM 412					
0	25.47	17	15	52.5	0.005
1000	55.47	42	36	53.8	.010
2000	85.47	66	55	54.6	.020
3000	115.47	85	77	52.5	.030
4000	145.47	114	97	53.9	.040
5000	175.47	141	125	53.1	.055
6000	205.47	178	159	52.8	.070
7000	235.47	218	207	51.3	.090
8000	265.47	267	289	48.0	.110
9000	295.47	318	369	46.3	.140
10 000	325.47	368	468	44.0	.170
11 000	355.47	409	557	42.4	.195
12 000	385.47	442	634	41.1	.220
13 000	415.47	481	723	40.0	.250
14 000	445.47	519	802	39.3	.280
15 000	475.47	569	896	38.8	.310
16 000	505.47	604	979	38.2	.340
17 000	535.47	646	1050	38.1	.360
18 000	565.47	691	1128	38.0	.390
19 000	595.47	733	1207	37.8	.420
20 000	625.47	781	1292	37.7	.455
21 000	655.47	828	1383	37.5	.490
22 000	685.47	878	1492	37.0	.530

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 413					
0	25.88	16	17	47.9	0.010
1000	55.88	40	38	51.2	.020
2000	85.88	59	58	50.4	.030
3000	115.88	87	75	53.7	.040
4000	145.88	109	96	53.2	.050
5000	175.88	141	125	53.1	.060
6000	205.88	176	182	52.1	.075
7000	235.88	216	212	50.5	.095
8000	265.88	266	291	47.7	.120
9000	295.88	315	376	45.5	.145
10 000	325.88	362	458	44.1	.175
11 000	355.88	404	538	42.9	.200
12 000	385.88	441	617	41.7	.230
13 000	415.88	483	692	41.1	.260
14 000	445.88	524	764	40.7	.285
15 000	475.88	562	836	40.2	.310
16 000	505.88	602	918	39.6	.340
17 000	535.88	638	991	39.1	.365
18 000	565.88	683	1068	39.0	.395
19 000	595.88	725	1149	38.7	.425
20 000	625.88	767	1236	38.3	.455
21 000	655.88	810	1316	38.1	.480
22 000	685.88	901	1550	36.8	.555
20 000	625.88	854	1491	36.4	.580
BEAM 342					
0	24.44	19	19	46.9	0.005
1000	54.44	43	38	53.1	.015
1500	69.44	57	53	51.6	.020
2000	84.44	69	63	52.1	.025
3000	114.44	91	89	50.6	.030
3500	129.44	110	103	51.6	.040
4000	144.44	134	138	49.2	.050
4500	159.44	166	219	43.2	.070
5000	174.44	217	368	37.1	.100
5500	189.44	260	561	31.7	.160
6000	204.44	325	872	27.1	.220
6280	212.84	.....	1091	.....	.250
5300	183.44	389	1781	15.9	.320
BEAM 343					
0	24.44	21	17	55.1	0.010
1000	54.44	45	43	51.4	.020
1500	69.44	59	60	49.6	.025
2000	84.44	74	72	50.8	.035
2500	99.44	88	84	51.0	.040
3000	114.44	102	99	50.8	.045
3500	129.44	118	115	50.6	.050
4000	144.44	135	142	48.7	.060
4500	159.44	168	200	45.7	.085
5000	174.44	226	386	36.9	.135
5500	189.44	282	603	31.9	.185
5800	198.44	.....	773	.....	.285
5100	177.44	307	740	29.3	.345

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 344					
0	24.64	24	17	58.6	0.010
1000	54.64	55	39	58.4	.020
2000	84.64	84	65	56.5	.035
3000	114.64	120	101	54.3	.045
3500	129.64	138	126	52.3	.055
4000	144.64	170	183	48.1	.075
4500	159.64	223	332	40.2	.115
5000	174.64	293	610	32.5	.175
5500	189.64	338	786	30.1	.215
6000	204.64	382	947	28.8	.275
6500	219.64	420	1111	27.5	.325
6800	228.64	.....	1169	.....	.365
5700	195.64	413	1113	27.1	.415
BEAM 354					
0	24.64	19	17	52.5	0.010
1000	54.64	45	39	53.7	.020
2000	84.64	74	62	54.3	.030
3000	114.64	100	85	54.1	.040
4000	144.64	131	121	51.9	.050
5000	174.64	178	193	47.9	.075
6000	204.64	271	424	39.0	.136
7000	234.64	345	674	33.9	.200
8000	264.64	411	901	31.3	.260
9000	294.64	488	1142	30.0	.320
9500	312.64	.....	1456	.....	.370
8400	276.64	596	2207	21.3	.450
BEAM 355					
0	24.64	19	19	49.9	0.010
1000	54.64	43	39	52.5	.020
2000	84.64	68	60	53.3	.030
3000	114.64	94	80	53.9	.040
3500	129.64	109	94	53.7	.050−
4000	144.64	127	115	52.5	.050+
5000	174.64	166	168	49.7	.070
6000	204.64	257	434	37.1	.120
7000	234.64	332	709	31.9	.190
8000	264.64	398	921	30.2	.250
9000	294.64	457	1111	29.2	.300
10 000	324.64	513	1306	28.2	.360
10 450	338.14	.....	1444	.....	(.420)
8200	270.64	545	2046	21.0	.430

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 356					
0	24.44	23	19	54.9	0.005
1000	54.44	47	36	56.7	.020
2000	84.44	75	58	56.3	.030
3000	114.44	101	84	54.7	.040
3500	129.44	117	97	54.6	.045
4000	144.44	133	115	53.7	.050
4500	159.44	155	140	52.5	.060
5000	174.44	179	176	50.4	.070
5500	189.44	219	268	45.0	.090
6000	204.44	277	448	38.2	.135
7000	234.44	354	711	33.3	.200
8000	264.44	416	921	31.1	.260
9000	294.44	477	1123	29.8	.320
9950	322.94	.....	1431	.....	.380
8300	273.44	571	2209	20.5	.435
BEAM 366					
0	24.85	19	14	57.1	0.010
1000	54.85	43	34	55.8	.020
2000	84.85	71	56	56.0	.030
3000	114.85	98	82	54.4	.040
3500	129.85	112	101	52.5	.050
4000	144.85	125	113	52.5	.055
4600	162.85	142	130	52.1	.060
5000	174.85	159	145	52.3	.070
6000	204.85	203	205	49.8	.080
7000	234.85	277	386	41.8	.130
8000	264.85	338	600	36.0	.180
9000	294.85	396	785	33.5	.230
10 000	324.85	441	954	31.6	.270
11 000	354.85	488	1096	30.8	.310
12 000	384.85	547	1236	30.7	.360
13 000	414.85	596	1374	30.2	.400
13 950	443.35	.....	1562	.....	.470
11 000	354.85	651	2248	22.5	.490
BEAM 367					
0	25.26	16	19	45.3	0.010
1000	55.26	43	36	54.4	.020
2000	85.26	69	56	55.3	.025
3000	115.26	93	80	55.3	.035
4000	145.26	125	111	52.9	.045
5000	175.26	165	156	51.4	.065
6000	205.26	214	244	46.7	.090
7000	235.26	273	371	42.4	.125
8000	265.26	334	561	37.3	.175
9000	295.26	393	723	35.2	.220
10 000	325.26	441	860	33.9	.260
11 000	355.26	492	1009	32.8	.305
12 000	385.26	539	1137	32.2	.345
13 000	415.26	595	1279	31.7	.390
13 870	441.36	.....	1439	.....	.....
10 850	350.76	642	2265	22.1	.465

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 368					
0	25.06	19	14	57.1	0.010
1000	55.06	54	22	71.0	.020
2000	85.06	86	34	71.7	.030
3000	115.06	115	56	67.2	.040
3500	130.06	131	72	64.6	.050
4000	145.06	150	87	63.3	.055
4500	160.06	168	106	61.0	.060
5000	175.06	187	130	59.0	.070
6000	205.06	237	200	54.2	.090
7000	235.06	311	364	46.1	.135
8000	265.06	374	547	40.6	.185
9000	295.06	431	703	38.0	.235
10 000	325.06	481	843	36.3	.275
11 000	355.06	534	976	35.3	.320
12 000	385.06	581	1103	34.5	.365
13 000	415.06	635	1232	34.0	.405
13 890	441.76	.....	1390	.....	.....
10 800	349.06	692	2174	24.2	.480
BEAM 378					
0	26.28	23	28	45.7	0.015
1000	56.28	42	47	46.9	.025
2000	86.28	64	68	48.7	.040
3000	116.28	88	94	48.4	.050
4000	146.28	117	132	46.9	.065
5000	176.28	161	190	46.0	.080
6000	206.28	210	280	44.7	.110
7000	236.28	277	377	42.3	.150
8000	266.28	331	495	40.1	.195
9000	296.28	389	619	38.6	.235
10 000	326.28	443	743	37.4	.275
11 000	356.28	493	859	36.5	.315
12 000	386.28	542	973	35.8	.355
13 000	416.28	593	1090	35.2	.395
14 000	446.28	648	1210	34.9	.440
14 230	453.18	.....	.....	.....	.....
11 700	377.28	724	1926	27.3	.500
BEAM 379					
0	25.06	26	15	63.5	0.005
1000	55.06	51	41	55.2	.015
2000	85.06	77	62	55.4	.025
3000	115.06	107	87	55.1	.040
4000	145.06	134	118	53.1	.055
5000	175.06	171	168	50.4	.070
6000	205.06	216	239	47.4	.090
7000	235.06	282	361	43.9	.130
8000	265.06	341	499	40.6	.170
9000	295.06	393	632	38.4	.210
10 000	325.06	446	749	37.3	.255
11 000	355.06	501	870	36.3	.295
12 000	385.06	551	993	35.7	.335
13 000	415.06	604	1104	35.3	.375
14 000	445.06	657	1234	34.7	.420
14 850	470.56	.....	1364	.....	.480
12 000	385.06	648	1274	33.7	.505

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 380					
0	24.64	16	17	47.9	0.005
1000	54.64	47	39	54.8	.020
2000	84.64	74	62	54.3	.030
3000	114.64	104	87	54.3	.040
4000	144.64	136	120	53.1	.055
5000	174.64	180	173	50.9	.070
6000	204.64	229	248	48.0	.095
7000	234.64	288	371	43.7	.130
8000	264.64	347	532	39.5	.175
9000	294.64	401	685	36.9	.215
10 000	324.64	454	831	35.3	.260
11 000	354.64	504	954	34.6	.300
12 000	384.64	552	1082	33.9	.335
13 000	414.64	608	1224	33.2	.380
13 750	437.14	.....	1366	.....	.420
14 000	444.64	691	1568	30.6	.460
12 100	387.64	702	1974	26.2	.470
BEAM 390					
0	26.69	28	22	55.5	0.010
1000	56.69	49	33	59.9	.020
2000	86.69	55	70	44.1	.030
3000	116.69	82	71	53.5	.040
4000	146.69	114	86	57.0	.050
5000	176.69	146	105	58.3	.065
6000	206.69	195	163	54.5	.080
7000	236.69	246	225	52.3	.105
8000	266.69	313	322	49.3	.145
9000	296.69	369	427	46.3	.180
10 000	326.69	423	539	44.0	.220
11 000	356.69	480	635	43.0	.260
12 000	386.69	530	727	42.2	.290
13 000	416.69	583	825	41.4	.330
14 000	446.69	636	915	41.0	.365
15 000	476.69	686	1013	40.4	.405
16 000	506.69	733	1105	39.9	.435
16 980	536.09	.....	.....	.....	.....
14 400	458.69	813	1896	30.0	.510
BEAM 391					
0	25.47	26	12	68.3	0.005
1000	55.47	52	29	64.2	.015
2000	85.47	78	51	60.6	.025
3000	115.47	103	75	57.8	.035
4000	145.47	127	92	58.0	.045
5000	175.47	158	125	55.9	.060
6000	205.47	201	193	51.0	.080
7000	235.47	245	280	46.7	.105
8000	265.47	321	390	45.1	.140
9000	295.47	370	513	41.9	.170
10 000	325.47	436	622	41.2	.210
11 000	355.47	480	737	39.4	.245
12 000	385.47	535	853	38.1	.275
13 000	415.47	573	973	37.1	.310
14 000	445.47	620	1080	36.5	.345
15 000	475.47	663	1186	35.9	.380
16 000	505.47	714	1291	35.6	.415
17 000	535.47	760	1391	35.4	.455
17 440	548.67	.....	1487	.....	.490
14 500	460.47	808	2087	27.9	.515

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 392					
0	25.26	21	14	59.7	0.005
1000	55.26	43	44	49.6	.015
2000	85.26	65	78	48.7	.025
3000	115.26	89	91	49.4	.035
4000	145.26	115	120	48.9	.050
5000	175.26	145	154	48.5	.060
6000	205.26	184	221	45.5	.085
7000	235.26	236	309	43.3	.105
8000	265.26	292	422	40.9	.140
9000	295.26	357	564	38.8	.185
10 000	325.26	408	667	37.9	.220
11 000	355.26	464	768	37.6	.260
12 000	385.26	520	884	37.0	.295
13 000	415.26	570	986	36.6	.325
14 000	445.26	623	1094	36.3	.365
15 000	475.26	673	1202	35.9	.400
16 000	505.26	728	1309	35.7	.440
17 000	535.26	809	1533	34.5	.495
17 250	542.76	.....	1668	.....	.525
14 400	457.26	894	2528	26.1	.575
BEAM 402					
0	26.90	37	19	66.0	0.010
1000	56.90	54	30	64.3	.015
2000	86.90	81	46	63.9	.030
3000	116.90	109	61	64.0	.040
4000	146.90	137	83	62.3	.050
5000	176.90	169	108	61.2	.060
6000	206.90	206	145	58.8	.075
7000	236.90	247	195	55.9	.095
8000	266.90	299	277	51.9	.120
9000	296.90	352	372	48.6	.155
10 000	326.90	405	445	47.6	.185
11 000	356.90	449	570	44.1	.215
12 000	386.90	497	661	42.9	.250
13 100	419.90	551	764	41.9	.285
14 000	446.90	592	844	41.2	.315
15 000	476.90	633	928	40.5	.345
16 000	506.90	680	1014	40.1	.375
17 000	536.90	727	1102	39.7	.410
18 000	566.90	777	1185	39.6	.440
19 000	596.90	823	1295	38.9	.475
19 920	624.50	.....	.....	.....	.....
17 050	538.40	899	1938	31.7	.550
BEAM 403					
0	25.88	23	14	62.0	0.010
1000	55.88	54	29	65.1	.020
2000	85.88	84	48	63.5	.040
3000	115.88	110	70	61.1	.055
4000	145.88	135	96	58.4	.070
5000	175.88	163	121	57.4	.085
6000	205.88	211	181	53.8	.110
7000	235.88	252	244	50.8	.130
8000	265.88	308	344	47.2	.160
9000	295.88	357	456	43.9	.200
10 000	325.88	406	568	41.7	.230
11 100	358.88	457	679	40.2	.265
12 000	385.88	502	766	39.6	.300
13 000	415.88	550	852	38.9	.325
14 000	445.88	594	961	38.2	.360
15 000	475.88	642	1058	37.8	.390
16 000	505.88	692	1152	37.5	.425
17 000	535.88	740	1244	37.3	.455
18 000	565.88	791	1345	37.0	.490
19 000	595.88	849	1475	36.5	.525
19 860	621.68	.....	1675	.....	.....
17 100	538.88	763	1827	29.5	.595

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 404					
0	25.47	19	17	52.5	0.010
1000	55.47	43	39	52.5	.020
2000	85.47	68	60	53.3	.030
3000	115.47	96	79	54.8	.040
4000	145.47	120	101	54.3	.050
5000	175.47	147	126	53.8	.060
6000	205.47	186	171	52.1	.075
7000	235.47	236	239	49.7	.100
8000	265.47	289	333	46.5	.125
9000	295.47	335	431	43.8	.155
10 000	325.47	388	537	42.0	.190
11 000	355.47	442	646	40.6	.220
12 000	385.47	485	737	39.7	.255
13 000	415.47	535	826	39.3	.285
14 000	445.47	592	920	39.1	.320
15 000	475.47	631	998	38.8	.345
16 000	505.47	678	1084	38.5	.375
17 000	535.47	722	1174	38.1	.405
18 000	565.47	780	1274	38.0	.445
19 000	595.47	826	1374	37.5	.475
20 000	625.47	896	1568	36.4	.525
20 200	631.47	.....	1771	.....	.....
18 300	574.47	962	2166	30.7	.575
BEAM 414					
0	25.26	23	19	54.9	0.010
1000	55.26	47	36	56.7	.020
2000	85.26	77	58	57.0	.030
3000	115.26	101	75	57.3	.040
4000	145.26	129	96	57.4	.050
5000	175.26	161	121	57.1	.060
6000	205.26	196	157	55.5	.075
7000	235.26	245	221	52.6	.095
8000	265.26	289	287	50.2	.120
9000	295.26	342	374	47.8	.145
10 000	325.26	395	470	45.7	.175
11 000	355.26	441	554	44.3	.205
12 000	385.26	489	643	43.2	.235
13 000	415.26	538	733	42.3	.265
14 000	445.26	581	817	41.6	.295
15 000	475.26	625	892	41.2	.325
16 000	505.26	674	976	40.8	.355
17 000	535.26	719	1048	40.7	.385
18 000	565.26	761	1130	40.3	.415
19 000	595.26	810	1222	39.8	.445
20 000	625.26	861	1315	39.6	.480
21 000	655.26	948	1569	37.7	.525
21 410	667.56	.....	1916	.....	.585
18 700	586.26	1068	2441	30.4	.615
BEAM 415					
0	26.69	15	15	49.1	0.005
1000	56.69	37	38	49.2	.015
2000	86.68	56	53	51.1	.025
3000	116.69	79	71	52.5	.035
4000	146.69	107	92	53.8	.045
5000	176.69	132	115	53.5	.055
6000	206.69	171	152	52.8	.070
7000	236.69	212	200	51.5	.090
8000	266.69	258	258	50.0	.115
9000	296.69	304	334	47.6	.140
10 000	326.69	355	423	45.6	.170
11 000	356.69	401	503	44.4	.200
12 050	388.19	452	597	43.1	.230
13 000	416.69	493	673	42.3	.260
14 000	446.69	540	748	41.9	.285
15 000	476.69	581	822	41.4	.315
16 000	506.69	625	896	41.1	.340
17 000	536.69	668	970	40.8	.370
18 000	566.69	716	1050	40.6	.400
19 000	596.69	757	1121	40.3	.430
20 000	626.69	810	1222	39.9	.460
21 000	656.69	845	1397	37.7	.500
21 440	669.89	.....	.....	.....	.....
19 250	604.19	973	2295	29.8	.585

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 416					
0	25.26	21	17	55.1	0.010
1000	55.26	50	38	57.0	.020
2000	85.26	75	56	57.1	.030
3000	115.26	103	79	56.6	.040
4000	145.26	133	103	56.3	.055
5000	175.26	167	132	55.8	.065
6000	205.26	207	173	54.5	.085
7000	235.26	257	238	51.9	.105
8000	265.26	308	315	49.5	.125
9000	295.26	366	402	47.7	.160
10 000	325.26	418	487	46.2	.190
11 000	355.26	467	579	44.7	.215
12 000	385.26	522	682	43.4	.250
13 000	415.26	565	759	42.7	.275
14 000	445.26	609	839	42.1	.305
15 000	475.26	662	928	41.7	.340
16 000	505.26	704	1000	41.3	.365
17 000	535.26	752	1082	41.0	.395
18 000	565.26	797	1168	40.6	.425
19 000	595.26	855	1267	40.3	.460
20 000	625.26	904	1366	39.8	.495
21 000	655.26	1008	1651	37.9	.560
19 000	595.26	1124	2485	31.2	.635
BEAM 417					
0	20.73	42	34	55.1	0.015
500	35.73	75	65	53.6	.030
1000	50.73	107	97	52.5	.045
1500	65.73	143	123	53.8	.055
2000	80.73	179	161	52.7	.070
2500	95.73	229	209	52.3	.090
3000	110.73	285	296	49.1	.115
3500	125.73	365	439	45.4	.155
4000	140.73	454	595	43.3	.205
4500	155.73	531	728	42.2	.260
5000	170.73	600	853	41.3	.305
5500	185.73	688	1009	40.5	.370
5900	197.73	.....	1169	.....	.440
4600	158.73	683	1015	40.2	.445
BEAM 418					
0	20.93	45	29	60.6	0.010
500	35.93	82	55	59.8	.025
1000	50.93	113	80	58.5	.040
1500	65.93	145	108	57.3	.050
2000	80.93	182	147	55.4	.060
2500	95.93	228	188	54.8	.085
3000	110.93	276	248	52.7	.105
3500	125.93	346	349	49.8	.135
4000	140.93	440	533	45.7	.190
4500	155.93	522	677	43.5	.240
5000	170.93	591	829	41.6	.285
5500	185.93	674	976	40.8	.335
5900	197.93	.....	1132	.....	.385
5000	170.93	762	1564	32.8	.420
BEAM 419					
0	20.31	45	32	58.4	0.015
500	35.31	97	60	61.7	.035
1000	50.31	134	87	60.6	.045
1500	65.31	177	123	59.0	.060
2000	80.31	226	162	58.3	.080
2500	95.31	272	217	55.7	.095
3000	110.31	337	318	51.4	.125
3500	125.31	426	480	47.0	.165
4000	140.31	505	629	44.5	.210
4500	155.31	588	744	44.1	.255
5000	170.31	666	897	42.6	.305
5500	185.31	765	1062	41.9	.360
6000	200.31	840	1205	41.1	.410
6390	212.01	.....	1294	.....	.445
5100	173.31	799	1171	40.6	.455
BEAM 429					
0	21.14	37	24	60.7	0.010
1000	51.14	106	70	60.2	.035
2000	81.14	179	126	58.7	.060
2500	96.14	227	166	57.7	.075
3000	111.14	274	210	56.6	.090
3500	126.14	321	280	55.3	.110
4000	141.14	377	326	53.6	.135
4500	156.14	444	403	52.4	.160
5000	171.14	516	499	50.8	.190
5500	186.14	585	595	49.6	.225
6000	201.14	658	699	48.5	.275
7000	231.14	802	913	46.8	.350
8000	261.14	954	1125	45.9	.420
8500	276.14	1073	1311	45.0	.485
8700	282.14	.....	1405	.....	.520
7400	243.14	1155	1848	38.5	.540
BEAM 430					
0	21.14	41	26	61.4	0.010
1000	51.14	123	82	60.1	.040
2000	81.14	196	138	58.6	.060
2500	96.14	243	179	57.6	.087
3000	111.14	281	226	55.5	.100
3500	126.14	330	284	53.7	.125
4000	141.14	378	345	52.3	.145
4500	156.14	453	426	51.3	.175
5000	171.14	524	509	50.7	.210
5500	186.14	603	609	49.7	.240
6000	201.14	652	691	48.6	.275
7000	231.14	805	885	47.6	.350
8000	261.14	953	1089	46.7	.420
8500	276.14	1072	1236	46.5	.475
8760	283.94	.....	1362	.....	.520
7700	252.14	1219	1769	40.8	.540

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 431					
0	20.93	52	24	68.3	0.010
500	35.93	94	41	69.6	.035
1000	50.93	130	68	65.6	.045
1500	65.93	169	97	63.6	.060
2000	80.93	202	126	61.6	.080
2500	95.93	244	159	60.6	.090
3000	110.93	282	198	58.8	.110
3500	125.93	331	260	56.0	.130
4000	140.93	391	313	55.6	.155
4500	155.93	454	383	54.2	.175
5000	170.93	518	474	52.2	.210
5500	185.93	589	556	51.5	.245
6000	200.93	657	655	50.1	.280
6500	215.93	726	733	49.8	.305
7000	230.93	788	821	49.0	.345
7500	245.93	878	920	48.8	.395
8000	260.93	948	1010	48.4	.430
8500	275.93	1032	1113	48.1	.465
8940	289.13	.....	1234	.....	.505
7500	245.93	1013	1087	48.2	.525
BEAM 441					
0	20.52	50	27	64.9	0.015
1000	50.52	135	72	65.3	.035
2000	80.52	230	130	63.9	.070
2500	95.52	277	168	62.3	.090
3000	110.52	333	207	61.7	.110
3500	125.52	388	253	60.5	.130
4000	140.52	455	313	59.3	.150
4500	155.52	522	376	58.1	.170
5000	170.52	594	443	57.3	.200
5500	185.52	673	508	57.0	.230
6000	200.52	740	574	56.3	.255
7000	230.52	921	713	56.4	.315
8000	260.52	1104	884	55.5	.385
9000	290.52	1277	1029	55.4	.445
10 000	320.52	1487	1215	55.0	.525
10 500	335.52	1690	1414	54.5	.585
9700	311.52	1807	1810	50.0	.620
BEAM 442					
0	20.73	47	27	63.4	0.015
1000	50.73	120	67	64.2	.040
2000	80.73	201	121	62.4	.065
2500	95.73	249	159	61.1	.085
3000	110.73	299	198	60.2	.100
3500	125.73	347	236	59.5	.120
4000	140.73	398	280	58.7	.135
4500	155.73	462	335	58.0	.160
5000	170.73	525	397	56.9	.190
6000	200.73	661	523	55.8	.240
7000	230.73	801	655	55.0	.295
8000	260.73	963	800	54.6	.360
9000	290.73	1143	933	55.1	.425
10 000	320.73	1309	1070	55.0	.490
10 500	335.73	1471	1186	55.4	.540
10 750	343.23	1506	1231	55.0	.560
10 900	347.73	.....	1335	.....	.595
9800	314.73	1616	1713	48.6	.600

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 443					
0	20.73	43	32	57.2	0.020
1000	50.73	113	82	57.9	.050
2000	80.73	196	140	58.3	.070
2500	95.73	234	168	58.2	.085
3000	110.73	286	200	58.9	.105
3500	125.73	335	243	58.0	.120
4000	140.73	385	284	57.6	.135
4500	155.73	446	330	57.5	.160
5000	170.73	508	386	56.8	.180
6000	200.73	644	526	55.0	.240
7000	230.73	776	679	53.3	.295
8000	260.73	928	807	53.5	.355
9000	290.73	1069	928	53.5	.415
10 000	320.73	1258	1060	54.3	.495
10 500	335.73	1385	1188	53.8	.530
11 000	350.73	1488	1292	53.5	.575
11 470	364.83	.....	1458	.....	.625
10 000	320.73	1595	1826	46.6	.630
BEAM 453					
0	20.52	50	29	63.3	0.015
1000	50.52	136	77	63.8	.040
2000	80.52	223	137	61.9	.065
3000	110.52	318	207	60.6	.110
4000	140.52	437	308	58.7	.140
5000	170.52	570	427	57.2	.195
6000	200.52	711	557	56.1	.250
7000	230.52	886	685	56.4	.320
8000	260.52	1046	826	55.9	.380
9000	290.52	1242	959	56.4	.440
10 000	320.52	1440	1096	56.8	.510
11 000	350.52	1654	1246	57.0	.590
11 300	359.52	1818	1332	57.7	.640
11 470	364.62	1962	1465	57.3	.680
11 700	371.52	2082	1684	55.3	.740
10 400	332.52	2161	1976	52.2	.760
BEAM 454					
0	20.93	50	36	58.3	0.020
1000	50.93	137	87	61.2	.035
2000	80.93	216	140	60.7	.065
3000	110.93	313	214	59.4	.095
4000	140.93	427	306	58.2	.135
5000	170.93	561	431	56.5	.185
6000	200.93	707	547	56.4	.235
7000	230.93	850	679	55.6	.295
8000	260.93	1030	827	55.5	.365
9000	290.93	1212	968	55.6	.425
10 000	320.93	1431	1126	56.0	.515
11 000	350.93	1728	1357	56.0	.635
11 130	354.83	2027	1655	55.1	.765
10 400	332.93	2073	1646	55.7	.800

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 455					
0	20.93	43	31	57.9	0.010
1000	50.93	111	84	56.9	.040
2000	80.93	185	138	57.3	.065
3000	110.93	269	200	57.4	.095
4000	140.93	375	280	57.2	.130
5000	170.93	495	386	56.2	.175
6000	200.93	622	491	55.9	.225
7000	230.93	784	639	55.1	.290
8000	260.93	929	786	54.2	.350
9000	290.93	1082	942	53.5	.420
10 000	320.93	1268	1097	53.6	.500
11 000	350.93	1542	1335	53.6	.595
11 450	364.43	1713	1508	53.2	.665
10 750	343.43	1882	1986	48.7	.720
BEAM 465					
0	20.73	57	32	64.2	0.015
1000	50.73	146	79	64.9	.040
2000	80.73	232	128	64.4	.070
3000	110.73	316	188	62.7	.100
4000	140.73	415	260	61.5	.130
5000	170.73	528	357	59.7	.175
6000	200.73	659	463	58.7	.225
7000	230.73	806	578	58.2	.275
8000	260.73	975	713	57.8	.330
9000	290.73	1142	832	57.8	.385
10 000	320.73	1321	957	58.0	.460
11 000	350.73	1508	1077	58.3	.515
12 000	380.73	1790	1231	59.3	.605
12 500	395.73	2039	1444	58.5	.700
13 000	410.73	2240	1632	57.8	.750
13 100	413.73	.....	.....	.....	.....
12 000	380.73	2643	2256	54.0	.875
BEAM 466					
0	20.93	54	31	63.6	0.015
1000	50.93	128	79	61.9	.040
2000	80.93	194	125	60.8	.060
3000	110.93	286	193	59.7	.090
4000	140.93	376	262	58.9	.120
5000	170.93	491	369	57.1	.165
6000	200.93	616	477	56.3	.210
7000	230.93	750	562	57.2	.270
8000	260.93	894	680	56.8	.330
9000	290.93	1041	802	56.5	.390
10 000	320.93	1187	911	56.6	.450
11 000	350.93	1374	1046	56.8	.510
12 000	380.93	1566	1176	57.1	.590
12 500	395.93	1727	1291	57.2	.630
12 820	405.53	.....	1379	.....	.670
13 000	410.93	1933	1506	56.2	.700
13 080	413.33	.....	1544	.....	.720
13 460	424.73	.....	1906	.....	.810
12 400	392.93	2373	2198	51.9	.830

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 467					
0	20.93	43	29	59.5	0.015
1000	50.93	108	79	57.8	.035
2000	80.93	181	123	59.6	.065
3000	110.93	261	181	59.1	.090
4000	140.93	350	251	58.2	.120
5000	170.93	452	340	57.0	.160
6000	200.93	559	436	56.2	.200
7000	230.93	700	537	56.6	.250
8000	260.93	806	655	55.2	.320
9000	290.93	941	786	54.5	.375
10 000	320.93	1084	903	54.6	.430
11 000	350.93	1228	1012	54.8	.495
12 000	380.93	1412	1132	55.5	.555
12 500	395.93	1509	1193	55.9	.600
13 000	410.93	1600	1246	56.2	.635
13 500	425.93	1726	1318	56.7	.690
13 950	439.93	1946	1562	55.3	.780
14 100	443.93	.....	1762	.....	.845
12 900	407.93	2158	1997	51.9	.850
BEAM 477					
0	21.14	57	26	68.7	0.015
1000	51.14	126	68	64.9	.040
2000	81.14	202	115	63.7	.065
3000	111.14	278	174	61.5	.090
4000	141.14	375	239	61.1	.120
5000	171.14	461	316	59.3	.155
6000	201.14	572	409	58.3	.195
7000	231.14	694	504	57.9	.235
8000	261.14	828	612	57.5	.280
9000	291.14	975	709	57.9	.335
10 000	321.14	1141	821	58.2	.380
11 000	351.14	1307	938	58.2	.460
12 000	381.14	1475	1050	58.4	.520
13 000	411.14	1668	1179	58.6	.575
14 000	441.14	2077	1409	59.6	.705
14 500	456.14	2298	1545	59.8	.765
14 870	467.24	2684	1925	58.2	.885
13 700	432.14	3024	2455	55.2	.955
BEAM 478					
0	20.93	47	24	66.0	0.015
1000	50.93	118	67	63.8	.035
2000	80.93	197	115	63.1	.055
3000	110.93	278	158	62.4	.085
4000	140.93	370	227	62.0	.120
5000	170.93	468	303	60.7	.150
6000	200.93	574	383	60.0	.185
7000	230.93	693	477	59.2	.230
8000	260.93	822	573	58.9	.280
9000	290.93	963	696	58.0	.330
10 000	320.93	1113	812	57.8	.380
11 000	350.93	1297	930	58.2	.435
12 000	380.93	1467	1043	58.5	.515
13 000	410.93	1661	1198	58.2	.580
14 000	440.93	1958	1403	58.3	.690
14 500	455.93	2285	1641	56.2	.815
14 590	458.63	2387	1701	58.4	.870
13 500	425.93	2390	1648	59.2	.885

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 479					
0	20.93	48	26	64.7	0.015
1000	50.93	117	65	64.3	.045
2000	80.93	195	115	62.8	.070
3000	110.93	275	162	62.9	.090
4000	140.93	368	231	61.4	.125
5000	170.93	457	296	60.7	.155
6000	200.93	566	386	59.4	.195
7000	230.93	689	475	59.2	.235
8000	260.93	809	573	58.5	.275
9000	290.93	959	677	58.6	.355
10 000	320.93	1088	768	58.6	.400
11 000	350.93	1254	880	58.8	.455
12 000	380.93	1418	997	58.7	.510
13 000	410.93	1598	1097	59.3	.590
14 000	440.93	1818	1243	59.4	.650
14 500	455.93	2008	1340	60.0	.700
14 830	465.83	2153	1455	59.7	.775
14 800	464.93	2279	1624	58.4	.805
15 000	470.93	2464	1795	57.9	.845
15 170	476.03	.....	1969	.....	.875
13 600	428.93	2679	2215	54.7	.885
BEAM 489					
0	21.14	61	31	66.2	0.005
1000	51.14	133	68	66.2	.030
2000	81.14	217	115	65.3	.060
3000	111.14	305	164	65.1	.085
4000	141.14	400	229	63.6	.110
5000	171.14	508	297	63.1	.150
6000	201.14	628	381	62.3	.185
7000	231.14	792	482	62.2	.235
8000	261.14	910	573	61.4	.270
9000	291.14	1083	672	61.7	.330
10 000	321.14	1250	769	61.9	.380
11 000	351.14	1428	868	62.2	.435
12 000	381.14	1650	983	62.7	.510
13 000	411.14	1844	1094	62.8	.575
14 000	441.14	2112	1219	63.4	.650
15 000	471.14	2510	1381	64.5	.755
15 100	474.14	.....	.....	.....	.800
15 320	480.74	.....	.....	.....	.855
15 500	486.14	3172	1805	63.7	.905
15 750	493.64	.....	2046	.....	.980
14 200	447.14	3718	2168	63.2	.990
BEAM 490					
0	21.34	45	32	58.4	0.015
1000	51.34	116	75	60.6	.025
2000	81.34	199	121	62.2	.055
3000	111.34	278	174	61.5	.080
4000	141.34	363	239	60.3	.110
5000	171.34	462	304	60.3	.140
6000	201.34	580	383	60.2	.175
7000	231.34	700	479	59.4	.225
8000	261.34	829	574	59.1	.265
9000	291.34	967	662	59.3	.315
10 000	321.34	1126	769	59.4	.375
11 000	351.34	1291	860	60.0	.440
12 000	381.34	1459	954	60.5	.495
13 000	411.34	1641	1055	60.9	.545
14 000	441.34	1891	1176	61.7	.640
15 000	471.34	2215	1318	62.7	.720
15 500	486.34	2414	1417	63.0	.765
15 700	492.34	.....	.....	.....	.850
15 820	495.94	.....	.....	.....	.....
16 000	501.34	3242	1974	62.2	1.005
14 600	459.34	3629	2152	62.8	1.090

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 491					
0	21.34	45	31	59.1	0.015
1000	51.34	112	77	59.4	.045
2000	81.34	179	118	60.2	.065
3000	111.34	252	166	60.3	.090
4000	141.34	328	219	60.0	.110
5000	171.34	411	282	59.3	.145
6000	201.34	511	344	59.8	.180
7000	231.34	615	438	58.4	.210
8000	261.34	755	530	58.8	.260
9000	291.34	884	622	58.7	.310
10 000	321.34	1020	711	58.9	.350
11 000	351.34	1175	827	58.7	.415
12 000	381.34	1329	918	59.2	.465
13 000	411.34	1506	1029	59.4	.515
14 000	441.34	1765	1145	60.6	.610
15 000	471.34	2109	1313	61.6	.700
15 500	486.34	2335	1417	62.2	.770
15 950	499.84	.....	.....	.....	.830
16 000	501.34	2748	1646	62.5	.860
16 350	511.84	.....	.....	.....	.930
16 410	513.64	.....	1993	.....	1.000
14 800	465.34	3923	2477	61.3	1.115
BEAM 420					
0	20.52	45	27	62.3	0.015
1000	50.52	113	75	60.2	.045
2000	80.52	184	137	57.3	.070
2500	95.52	228	185	55.2	.085
3000	110.52	268	234	53.4	.105
3500	125.52	315	313	50.2	.125
4000	140.52	381	398	48.9	.155
4500	155.52	461	564	45.0	.195
5000	170.52	541	745	42.1	.245
5500	185.52	614	933	39.7	.295
6000	200.52	674	1085	38.3	.345
6120	204.12	.....	1265	.....	.395
5500	185.52	760	1557	32.8	.415
BEAM 421					
0	21.34	42	27	61.1	0.010
1000	51.34	106	79	57.4	.040
2000	81.34	165	133	55.4	.065
2500	96.34	205	171	54.5	.080
3000	111.34	244	210	53.7	.095
3500	126.34	280	258	52.0	.115
4000	141.34	330	337	49.5	.140
4500	156.34	404	492	45.1	.185
5000	171.34	482	711	40.4	.240
5500	186.34	543	875	38.3	.280
5880	197.74	.....	1044	.....	.340
5100	174.34	623	1475	29.7	.380

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 422					
0	20.93	47	31	60.2	0.015
1000	50.93	114	79	59.0	.040
2000	80.93	182	142	56.2	.070
2500	95.93	224	188	54.3	.085
3000	110.93	264	238	52.6	.105
3500	125.93	316	297	51.5	.130
4000	140.93	367	378	49.3	.150
4500	155.93	445	554	44.5	.200
5000	170.93	520	757	40.7	.250
5500	185.93	596	959	38.3	.305
5840	196.13	.....	1070	.....	.340
5860	196.73	.....	1197	.....	.360
5300	179.93	678	1450	31.8	.390
BEAM 432					
0	21.55	42	29	58.9	0.015
1000	51.55	95	74	56.3	.035
2000	81.55	158	126	55.7	.060
3000	111.55	227	178	56.1	.090
4000	141.55	294	253	53.8	.115
4500	156.55	344	311	52.5	.140
5000	171.55	398	376	51.4	.160
5500	186.55	451	463	49.3	.180
6000	201.55	495	540	47.8	.205
7000	231.55	614	762	44.6	.260
8000	261.55	736	974	43.1	.330
8730	283.45	815	1162	41.2	.400
8810	285.85	.....	1219	.....	.420
7800	255.35	783	1138	40.8	.430
BEAM 433					
0	21.76	39	27	59.3	0.010
1000	51.76	92	72	56.2	.035
2000	81.76	145	118	55.2	.060
3000	111.76	202	173	53.8	.080
4000	141.76	267	248	51.8	.110
4500	156.76	314	294	51.7	.130
5000	171.76	351	340	50.8	.150
5500	186.76	396	410	49.2	.170
6000	201.76	450	497	47.5	.200
6500	216.76	500	583	46.2	.230
7000	231.76	554	687	44.6	.260
8000	261.76	652	872	42.8	.320
9000	291.76	778	1101	41.4	.400
9400	303.76	.....	1214	.....	.440
9400	303.76	.....	1231	.....	.450

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 434					
0	21.14	42	29	58.9	0.015
1000	51.14	100	65	60.7	.035
2000	81.14	164	115	58.8	.060
3000	111.14	230	171	57.4	.080
3500	126.14	266	203	56.8	.100
4000	141.14	304	232	56.7	.110
4500	156.14	342	272	55.7	.130
5000	171.14	390	321	54.8	.150
5500	186.14	434	386	52.9	.170
6000	201.14	511	463	52.4	.200
6500	216.14	561	545	50.7	.230
7000	231.14	612	619	49.7	.260
8000	261.14	728	826	46.8	.325
9000	291.14	842	1065	44.2	.400
9270	299.24	.....	1200	.....	.435
8200	267.14	910	1526	37.3	.445
BEAM 444					
0	21.34	42	31	57.3	0.015
1000	51.34	100	67	60.0	.035
2000	81.34	164	111	59.6	.060
3000	111.34	232	168	58.0	.090
4000	141.34	305	229	57.2	.115
5000	171.34	385	316	54.9	.150
6000	201.34	471	427	52.4	.190
7000	231.34	575	562	50.6	.240
8000	261.34	665	697	48.8	.290
9000	291.34	772	855	47.5	.345
10 000	321.34	879	997	46.8	.400
11 000	351.34	991	1138	46.5	.460
12 000	381.34	1111	1285	46.4	.515
9900	318.34	1163	1956	37.3	.....
BEAM 445					
0	21.34	37	27	58.0	0.015
1000	51.34	93	72	56.4	.040
2000	81.34	154	123	55.6	.060
3000	111.34	205	168	54.9	.080
4000	141.34	279	238	54.0	.115
5000	171.34	356	333	51.8	.150
6000	201.34	449	434	50.9	.190
7000	231.34	529	564	48.4	.235
8000	261.34	625	718	46.7	.285
9000	291.34	723	852	45.6	.335
10 000	321.34	819	995	45.1	.385
11 000	351.34	931	1154	44.4	.455
11 750	373.84	.....	1381	.....	.525
9900	318.34	1068	1991	34.9	.535

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 446					
0	21.34	42	26	62.0	0.015
1000	51.34	105	74	58.6	.040
2000	81.34	166	118	58.5	.060
3000	111.34	238	174	57.7	.085
4000	141.34	313	253	55.3	.115
5000	171.34	388	338	53.5	.150
6000	201.34	478	455	51.2	.190
7000	231.34	576	586	49.6	.235
8000	261.34	674	737	47.7	.285
9000	291.34	783	899	46.6	.340
10 000	321.34	888	1044	45.9	.395
11 000	351.34	1014	1209	45.6	.450
12 000	381.34	1159	1482	43.9	.535
10 300	330.34	1182	1831	39.2	.560
BEAM 456					
0	21.14	42	27	61.1	0.015
1000	51.14	110	72	60.3	.040
2000	81.14	173	115	60.1	.065
3000	111.14	242	166	59.4	.090
4000	141.14	318	222	58.9	.120
5000	171.14	405	313	56.4	.150
6000	201.14	495	409	54.8	.190
7000	231.14	593	532	52.7	.235
8000	261.14	697	668	51.1	.280
9000	291.14	806	802	50.1	.330
10 000	321.14	916	932	49.6	.385
11 000	351.14	1020	1062	49.0	.435
12 000	381.14	1184	1244	48.8	.500
12 500	396.14	.....	1482	.....	.550
11 200	357.14	1325	1809	42.3	.565
BEAM 457					
0	21.76	32	24	57.0	0.010
1000	51.76	93	67	58.1	.035
2000	81.76	145	111	56.6	.055
3000	111.76	216	156	58.0	.080
4000	141.76	283	215	56.8	.115
5000	171.76	362	285	56.0	.140
6000	201.76	454	388	53.9	.180
7000	231.76	549	504	52.1	.225
8000	261.76	643	641	50.1	.270
9000	291.76	739	776	48.8	.320
10 000	321.76	834	901	48.1	.365
11 000	351.76	942	1029	47.5	.415
12 000	381.76	1055	1173	47.4	.470
13 000	411.76	1181	1320	47.2	.535
14 000	441.76	1348	1571	46.2	.615
11 550	368.26	1239	1366	47.6	.645

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 458					
0	21.55	38	34	52.5	0.015
1000	51.55	108	74	59.4	.035
2000	81.55	172	120	58.8	.060
3000	111.55	243	179	57.6	.090
4000	141.55	319	239	57.2	.115
5000	171.55	402	318	55.8	.150
6000	201.55	496	412	54.6	.190
7000	231.55	611	532	53.5	.240
8000	261.55	708	663	51.6	.290
9000	291.55	812	797	50.5	.340
10 000	321.55	919	938	49.5	.390
11 000	351.55	1043	1079	49.2	.445
12 000	381.55	1183	1221	49.2	.510
12 920	409.15	.....	1405	.....	.570
13 000	411.55	1384	1515	47.7	.590
13 200	417.55	.....	1610	.....	.620
12 200	387.55	1471	1976	42.7	.625
BEAM 468					
0	21.34	37	29	56.3	0.010
1000	51.34	93	63	59.6	.025
2000	81.34	155	97	61.4	.045
3000	111.34	220	140	61.1	.070
4000	141.34	289	191	60.2	.105
5000	171.34	366	255	58.9	.125
6000	201.34	448	333	57.4	.160
7000	231.34	550	427	56.3	.200
8000	261.34	646	520	55.4	.235
9000	291.34	753	624	54.7	.305
10 000	321.34	847	721	54.0	.345
11 000	351.34	964	822	54.0	.395
12 000	381.34	1063	918	53.7	.440
13 000	411.34	1185	1024	53.6	.490
14 000	441.34	1317	1128	53.9	.550
14 560	458.14	.....	1188	.....	.585
13 600	429.34	1434	1130	55.9	.630
BEAM 469					
0	21.34	35	27	56.5	0.015
1000	51.34	95	65	59.4	.035
2000	81.34	158	108	59.4	.055
3000	111.34	222	154	59.0	.080
4000	141.34	292	212	58.0	.110
5000	171.34	378	275	57.9	.135
6000	201.34	463	361	56.2	.175
7000	231.34	557	460	54.8	.215
8000	261.34	656	564	53.8	.255
9000	291.34	758	668	53.2	.295
10 000	321.34	865	769	52.9	.345
11 000	351.34	974	873	52.7	.395
12 000	381.34	1081	979	52.5	.440
13 000	411.34	1222	1096	52.7	.500
14 000	441.34	1360	1209	52.9	.555
14 550	457.84	.....	1296	.....	.595
12 900	408.34	1608	2002	44.5	.665

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 470					
0	21.14	35	31	53.3	0.015
1000	51.14	98	74	56.9	.035
2000	81.14	166	116	58.9	.050
3000	111.14	227	166	57.7	.070
4000	141.14	303	221	57.8	.100
5000	171.14	380	285	57.2	.130
6000	201.14	466	369	55.8	.160
7000	231.14	568	474	54.5	.200
8000	261.14	662	574	53.5	.240
9000	291.14	765	687	52.7	.280
10 000	321.14	870	807	51.9	.320
11 000	351.14	980	926	51.4	.365
12 000	381.14	1090	1044	51.1	.450
13 000	411.14	1246	1178	51.4	.510
14 000	441.14	1399	1344	51.0	.570
14 250	448.64	.....	1402	.....	.600
14 500	456.14	.....	1509	.....	.620
15 000	471.14	1662	1747	48.7	.670
13 500	426.14	1724	2156	44.4	.700
BEAM 480					
0	21.55	35	26	57.4	0.020
1000	51.55	100	65	60.7	.040
2000	81.55	163	108	60.1	.060
3000	111.55	224	156	58.9	.080
4000	141.55	295	202	59.3	.105
5000	171.55	369	260	58.7	.135
6000	201.55	443	323	57.8	.165
7000	231.55	521	393	57.0	.195
8000	261.55	614	479	56.2	.235
9000	291.55	702	562	55.5	.270
10 000	321.55	792	651	54.9	.310
11 000	351.55	883	742	54.3	.345
12 000	381.55	985	838	54.0	.390
13 000	411.55	1078	928	53.7	.430
14 000	441.55	1184	1019	53.7	.470
15 000	471.55	1297	1125	53.6	.515
16 000	501.55	1478	1280	53.6	.580
16 650	521.05	.....	1547	.....	.645
15 000	471.55	1750	2068	45.8	.685
BEAM 482					
0	20.93	35	24	59.3	0.015
1000	50.93	99	58	63.0	.030
2000	80.93	160	94	62.9	.050
3000	110.93	225	138	62.0	.075
4000	140.93	294	190	60.8	.095
5000	170.93	362	244	59.8	.115
6000	200.93	437	308	58.7	.140
7000	230.93	517	379	57.7	.215
8000	260.93	615	463	57.0	.250
9000	290.93	711	549	56.4	.285
10 000	320.93	804	632	56.0	.325
11 000	350.93	903	713	55.9	.350
12 000	380.93	1011	793	56.0	.400
13 000	410.93	1122	885	55.9	.440
14 000	440.93	1226	974	55.7	.480
15 000	470.93	1355	1053	56.0	.525
16 000	500.93	1511	1183	56.1	.580
16 650	520.43	.....	1366	.....	.635
17 000	530.93	1782	1520	54.0	.665
17 300	539.93	.....	1677	.....	.700
17 500	545.93	.....	1785	.....	.775
16 100	503.93	2009	2190	48.6	.810

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 492					
0	21.55	32	27	54.2	0.015
1000	51.55	95	67	58.7	.035
2000	81.55	153	106	59.1	.060
3000	111.55	218	149	59.4	.080
4000	141.55	289	200	59.1	.105
5000	171.55	354	250	59.3	.130
6000	201.55	440	308	58.8	.160
7000	231.55	520	374	58.1	.190
8000	261.55	610	453	57.4	.225
9000	291.55	703	538	56.6	.255
10 000	321.55	801	626	56.1	.295
11 000	351.55	899	708	55.9	.335
12 000	381.55	999	797	55.6	.375
13 000	411.55	1112	887	55.6	.415
14 000	441.55	1236	978	55.8	.455
15 000	471.55	1355	1067	55.9	.500
16 000	501.55	1487	1164	56.1	.550
17 000	531.55	1694	1347	55.7	.615
18 000	561.55	1906	1545	55.2	.680
14 000	441.55	1754	1385	55.9	.605
15 000	471.55	1814	1439	55.8	.625
16 000	501.55	1877	1497	55.6	.650
17 000	531.55	1944	1559	55.5	.675
18 000	561.55	2056	1667	55.2	.740
18 060	563.35	.....	1726	.....	.760
18 060	563.35	.....	1950	.....	.795
17 000	531.55	2301	2316	49.8	.820
BEAM 493					
0	21.96	43	29	58.9	0.015
1000	51.96	103	68	60.1	.055
2000	81.96	157	104	60.2	.075
3000	111.96	223	144	60.8	.095
4000	141.96	279	186	60.0	.120
5000	171.96	345	236	59.4	.145
6000	201.96	416	291	59.0	.175
7000	231.96	503	354	58.7	.200
8000	261.96	591	429	57.9	.240
9000	291.96	681	504	57.5	.275
10 000	321.96	783	585	57.2	.315
11 000	351.96	879	662	57.0	.355
12 000	381.96	978	745	56.8	.390
13 000	411.96	1103	851	56.4	.440
14 000	441.96	1193	935	56.1	.475
15 000	471.96	1324	1024	56.4	.525
16 000	501.96	1436	1116	56.3	.565
17 000	531.96	1596	1224	56.6	.625
17 410	544.26	.....	1311	.....	.670
17 850	557.46	1866	1431	56.6	.730
17 880	558.36	.....	1600	.....	.785
15 800	525.96	2034	1680	54.8	.805
BEAM 494					
0	21.76	42	26	62.0	0.010
1000	51.76	104	65	61.6	.035
2000	81.76	170	108	61.1	.060
3000	111.76	234	149	61.1	.080
4000	141.76	302	197	60.5	.100
5000	171.76	377	253	59.6	.130
6000	201.76	452	308	59.5	.165
7000	231.76	534	374	58.8	.195
8000	261.76	628	453	58.1	.225
9000	291.76	721	533	57.5	.260
10 000	321.76	809	614	56.9	.295
11 000	351.76	909	697	56.6	.340
12 000	381.76	1011	781	56.4	.375
13 000	411.76	1126	868	56.5	.415
14 000	441.76	1240	956	56.5	.455
15 000	471.76	1367	1048	56.6	.505
16 000	501.76	1501	1149	56.6	.555
17 000	531.76	1746	1374	56.0	.635
17 500	546.76	.....	1515	.....	.685
17 800	555.76	2005	1651	54.8	.725
17 950	560.26	.....	1705	.....	.765
18 000	561.76	2135	1769	54.7	.780
18 140	565.96	.....	1807	.....	.805
16 300	510.76	2339	2200	50.4	.830

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 423					
0	21.34	37	29	56.3	0.010
1000	51.34	90	67	57.3	.030
2000	81.34	148	108	57.8	.050
2500	96.34	177	132	57.3	.065
3000	111.34	214	169	55.9	.080
3500	126.34	246	202	55.0	.090
4000	141.34	282	243	53.7	.105
4500	156.34	328	308	51.6	.125
5000	171.34	381	398	48.9	.150
5500	186.34	458	603	43.2	.210
6000	201.34	536	788	30.5	.260
6500	216.34	591	933	38.8	.310
6610	219.64	.....	1101	.....	.360
5100	174.34	602	1897	24.1	.400
BEAM 424					
0	21.14	32	21	60.1	0.015
1000	51.14	84	56	60.0	.035
2000	81.14	133	99	57.2	.055
2500	96.14	171	126	57.6	.065
3000	111.14	206	162	56.0	.080
3500	126.14	239	195	55.0	.095
4000	141.14	274	238	53.5	.110
4500	156.14	325	328	49.7	.135
5000	171.14	392	467	45.6	.175
5500	186.14	464	680	40.6	.225
6000	201.14	525	848	38.2	.280
6460	214.94	.....	945	.....	.335
5200	177.14	489	855	36.4	.340
BEAM 425					
0	21.14	45	34	56.9	0.010
1000	51.14	98	77	55.9	.035
2000	81.14	154	128	54.6	.060
2500	96.14	183	157	53.8	.070
3000	111.14	211	191	52.5	.080
3500	126.14	248	232	51.7	.100
4000	141.14	289	294	49.6	.120
4500	156.14	335	381	46.8	.140
5000	171.14	409	585	41.1	.190
5500	186.14	476	756	38.6	.240
6000	201.14	534	904	37.1	.290
6320	210.74	.....	1029	.....	.330
5100	174.14	499	899	35.7	.350

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 435					
0	20.93	37	29	56.3	0.010
1000	50.93	100	72	58.0	.035
2000	80.93	153	115	57.2	.050
2500	95.93	191	140	57.6	.065
3000	110.93	229	169	57.5	.080
3500	125.93	259	195	57.0	.090
4000	140.93	296	231	56.2	.105
4500	155.93	329	270	54.9	.120
5000	170.93	379	328	53.6	.140
5500	185.93	432	405	51.6	.165
6000	200.93	479	480	49.9	.190
7000	230.93	577	646	47.2	.240
8000	260.93	673	831	44.8	.300
9000	290.93	786	1019	43.6	.370
9500	305.93	.....	1210	.....	.420
7650	250.43	863	1798	32.4	.440
BEAM 436					
0	21.34	32	29	52.5	0.015
1000	51.34	88	65	57.4	.035
2000	81.34	138	113	54.9	.055
2500	96.34	172	137	55.7	.070
3000	111.34	199	159	55.6	.080
3500	126.34	230	188	55.0	.090
4000	141.34	266	224	54.2	.110
4500	156.34	298	267	52.8	.125
5000	171.34	337	326	50.8	.140
5500	186.34	383	390	49.5	.160
6000	201.34	430	470	47.8	.190
7000	231.34	533	655	44.9	.240
8000	261.34	631	863	42.2	.305
9000	291.34	724	1072	40.3	.375
9300	300.34	.....	1202	.....	.410
8000	261.34	699	1096	38.9	.420
BEAM 437					
0	20.93	30	27	52.5	0.015
1000	50.93	90	67	57.3	.035
2000	80.93	143	113	55.8	.055
2500	95.93	173	138	55.6	.065
3000	110.93	207	171	54.8	.080
3500	125.93	239	203	54.1	.095
4000	140.93	277	244	53.2	.110
4500	155.93	318	296	51.8	.130
5000	170.93	361	350	50.7	.150
6000	200.93	451	501	47.3	.200
7000	230.93	545	675	44.7	.255
8000	260.93	634	867	42.2	.315
9000	290.93	738	1056	41.1	.380
9550	307.43	.....	1253	.....	.435
8200	266.93	828	1668	33.2	.455

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 447					
0	20.73	35	24	59.3	0.010
1000	50.73	90	65	58.0	.030
2000	80.73	151	106	58.7	.050
3000	110.73	211	144	59.4	.070
4000	140.73	277	193	58.7	.100
5000	170.73	345	258	57.2	.125
6000	200.73	429	342	55.6	.160
7000	230.73	514	431	54.4	.190
8000	260.73	603	549	52.3	.230
9000	290.73	690	680	50.4	.280
10 000	320.73	784	815	49.0	.335
11 000	350.73	882	938	48.5	.383
12 000	380.73	986	1096	47.4	.440
12 600	398.73	.....	1254	.....	.500
10 700	341.73	1085	1626	37.3	.510
BEAM 448					
0	21.14	34	19	63.9	0.010
1000	51.14	92	60	60.4	.030
2000	81.14	137	97	58.5	.050
3000	111.14	185	137	57.5	.075
4000	141.14	253	188	57.4	.100
5000	171.14	317	248	56.1	.130
6000	201.14	379	330	53.5	.155
7000	231.14	478	448	51.6	.195
8000	261.14	561	578	49.3	.240
9000	291.14	639	715	47.2	.290
10 000	321.14	727	851	46.1	.340
11 000	351.14	826	995	45.4	.395
12 000	381.14	916	1120	45.0	.445
12 830	406.04	.....	1311	.....	.515
10 700	342.14	895	1197	42.8	.520
BEAM 449					
0	21.14	32	26	55.1	0.010
1000	51.14	92	63	59.3	.030
2000	81.14	146	106	57.9	.050
3000	111.14	204	149	57.7	.070
4000	141.14	264	196	57.5	.090
5000	171.14	334	262	56.0	.120
6000	201.14	401	338	54.3	.150
7000	231.14	490	455	51.9	.190
8000	261.14	581	573	50.3	.230
9000	291.14	669	701	48.8	.280
10 000	321.14	764	839	47.7	.330
11 000	351.14	845	976	46.4	.380
12 000	381.14	944	1109	46.0	.430
13 000	411.14	.....	1376	.....	.510
11 000	351.14	1187	2484	32.0	.580

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 459					
0	21.14	34	22	60.6	0.015
1000	51.14	86	56	60.6	.030
2000	81.14	140	103	57.6	.050
3000	111.14	202	144	58.4	.075
4000	141.14	258	188	57.9	.095
5000	171.14	326	248	56.8	.120
6000	201.14	397	325	55.0	.150
7000	231.14	485	432	52.9	.190
8000	261.14	574	545	51.3	.230
9000	291.14	665	672	49.7	.275
10 000	321.14	770	800	49.0	.325
11 000	351.14	868	926	48.4	.370
12 000	381.14	959	1051	47.7	.415
13 000	411.14	1075	1195	47.4	.470
13 730	433.04	.....	1315	.....	.525
12 000	381.04	1245	1436	46.4	.620
BEAM 460					
0	21.14	34	24	58.5	0.010
1000	51.14	90	63	58.7	.030
2000	81.14	140	99	58.6	.050
3000	111.14	196	140	58.3	.070
4000	141.14	253	191	57.0	.095
5000	171.14	318	256	55.4	.120
6000	201.14	398	345	53.6	.150
7000	231.14	480	446	51.9	.190
8000	261.14	566	569	49.9	.230
9000	291.14	658	711	48.1	.280
10 000	321.14	744	839	47.0	.330
11 000	351.14	830	961	46.3	.370
12 000	381.14	914	1096	45.5	.420
13 000	411.14	1006	1234	44.9	.470
13 980	440.54	.....	1385	.....	.530
12 250	388.64	1144	1937	37.1	.550
BEAM 461					
0	20.93	32	26	55.1	0.015
1000	50.93	86	58	59.8	.035
2000	80.93	138	104	57.0	.060
3000	110.93	206	147	58.3	.080
4000	140.93	266	202	56.9	.105
5000	170.93	336	267	55.7	.135
6000	200.93	421	352	54.7	.170
7000	230.93	519	462	52.9	.220
8000	260.93	609	576	51.4	.260
9000	290.93	714	708	50.2	.310
10 000	320.93	815	832	49.5	.360
11 000	350.93	913	959	48.8	.410
12 000	380.93	1014	1084	48.3	.460
13 000	410.93	1117	1221	47.8	.525
13 100	413.93	.....	1272	.....	.570
11 500	365.93	1118	1205	48.1	.580

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 471					
0	21.14	41	26	61.4	0.010
1000	51.14	92	60	50.4	.030
2000	81.14	149	97	60.6	.050
3000	111.14	205	138	59.8	.070
4000	141.14	273	186	59.5	.095
5000	171.14	337	244	58.0	.120
6000	201.14	409	306	57.2	.145
7000	231.14	495	376	56.8	.180
8000	261.14	587	451	56.5	.215
9000	291.14	681	550	55.3	.255
10 000	321.14	781	662	54.1	.300
11 000	351.14	880	768	53.4	.340
12 000	381.14	969	870	52.7	.380
13 000	411.14	1074	988	52.1	.425
14 000	441.14	1182	1109	51.6	.475
15 000	471.14	1308	1270	50.7	.535
15 400	483.14	.....	1545	.....	.585
13 400	423.14	1585	2831	35.9	.690
BEAM 472					
0	21.14	35	21	62.4	0.015
1000	51.14	90	65	58.0	.035
2000	81.14	142	104	57.8	.055
3000	111.14	198	142	58.2	.075
4000	141.14	261	188	58.2	.100
5000	171.14	320	239	57.2	.125
6000	201.14	394	299	56.8	.150
7000	231.14	466	373	55.5	.180
8000	261.14	548	467	54.0	.220
9000	291.14	631	566	52.7	.260
10 000	321.14	721	670	51.8	.300
11 000	351.14	810	781	50.9	.340
12 000	381.14	902	891	50.3	.385
13 000	411.14	1009	1012	49.9	.435
14 000	441.14	1119	1156	49.2	.485
15 000	471.14	1273	1381	48.0	.565
15 570	488.24	.....	1561	.....	.640
13 500	426.14	1423	2070	40.7	.660
BEAM 473					
0	21.14	32	24	57.0	0.010
1000	51.14	90	62	59.1	.030
2000	81.14	145	101	59.0	.055
3000	111.14	198	140	58.6	.075
4000	141.14	266	195	57.7	.105
5000	171.14	330	250	56.9	.130
6000	201.14	405	323	55.7	.160
7000	231.14	491	417	54.1	.195
8000	261.14	578	516	52.8	.230
9000	291.14	667	626	51.6	.275
10 000	321.14	757	735	50.7	.315
11 000	351.14	854	846	50.2	.360
12 000	381.14	965	978	49.7	.415
13 000	411.14	1051	1082	49.3	.460
14 000	441.14	1146	1195	49.0	.500
14 920	468.74	.....	1368	.....	.570
15 000	471.14	1340	1566	46.1	.590
13 400	423.14	1481	2316	39.0	.660

Applied Load, lbs.	M/bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 483					
0	21.34	35	24	59.3	0.010
1000	51.34	93	63	59.6	.030
2000	81.34	147	94	61.0	.050
3000	111.34	203	138	59.5	.070
4000	141.34	263	181	59.3	.095
5000	171.34	327	229	58.8	.120
6000	201.34	401	292	57.8	.145
7000	231.34	474	362	56.7	.175
8000	261.34	552	432	56.1	.210
9000	291.34	643	520	55.3	.240
10 000	321.34	737	609	54.8	.280
11 000	351.34	831	703	54.2	.325
12 000	381.34	930	802	53.7	.365
13 000	411.34	1021	892	53.4	.405
14 000	441.34	1134	1003	53.1	.455
15 000	471.34	1219	1091	52.8	.490
16 000	501.34	1371	1232	52.7	.550
17 000	531.34	.....	1638	.....	.655
15 900	498.34	1658	2065	44.5	.665
BEAM 484					
0	21.76	37	21	63.7	0.010
1000	51.76	86	58	59.8	.030
2000	81.76	142	92	60.6	.050
3000	111.76	200	133	60.0	.070
4000	141.76	261	178	59.5	.095
5000	171.76	321	227	58.6	.115
6000	201.76	388	289	57.3	.145
7000	231.76	463	359	56.3	.175
8000	261.76	541	444	54.9	.205
9000	291.76	624	530	54.1	.240
10 000	321.76	710	624	53.2	.275
11 000	351.76	797	716	52.7	.315
12 000	381.76	895	812	52.4	.355
13 000	411.76	992	908	52.2	.395
14 000	441.76	1093	1003	52.1	.440
15 000	471.76	1199	1101	52.1	.480
16 000	501.76	1314	1200	52.3	.530
17 000	531.76	1433	1308	52.3	.585
17 550	548.26	.....	1540	.....	.....
15 750	494.26	1526	1432	51.6	.685
BEAM 485					
0	21.55	37	22	62.7	0.010
1000	51.55	87	55	61.3	.030
2000	81.55	145	94	60.7	.050
3000	111.55	203	133	60.4	.075
4000	141.55	265	176	60.1	.095
5000	171.55	329	224	59.5	.120
6000	201.55	400	280	58.8	.145
7000	231.55	477	345	58.0	.175
8000	261.55	560	421	57.1	.210
9000	291.55	645	497	56.5	.245
10 000	321.55	738	586	55.7	.280
11 000	351.55	846	687	55.2	.325
12 000	381.55	937	779	54.6	.365
13 000	411.55	1034	875	54.2	.405
14 000	441.55	1137	971	53.9	.445
15 000	471.55	1249	1067	53.9	.490
16 100	504.55	1396	1219	53.4	.545
17 000	531.55	1574	1482	51.5	.615
15 700	492.55	1923	2641	42.1	.745

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	M / bd² lbs. per sq. in.	Deformation, millionths of inch per inch: Upper Fiber	Deformation, millionths of inch per inch: Steel Fiber	K, per cent	Deflection, inches
BEAM 495					
0	21.34	41	21	66.2	0.015
1000	51.34	94	55	63.2	.035
2000	81.34	150	85	63.8	.055
3000	111.34	207	121	63.2	.075
4000	141.34	272	164	62.4	.095
5000	171.34	335	209	61.6	.120
6000	201.34	406	258	61.2	.140
7000	231.34	478	313	60.4	.165
8000	261.34	556	376	59.6	.195
9000	291.34	652	448	59.3	.230
10 000	321.34	740	523	58.6	.260
11 000	351.34	838	603	58.2	.300
12 000	381.34	914	679	57.4	.330
13 000	411.34	1024	762	57.3	.370
14 000	441.34	1104	834	57.0	.....
15 000	471.34	1198	915	56.7	.445
16 000	501.34	1318	1002	56.8	.485
17 000	531.34	1409	1079	56.6	.520
18 100	564.34	1521	1174	56.4	.565
19 000	591.34	1675	1313	56.0	.620
19 730	613.24	.....	1602	.....	.680
18 100	564.34	1821	1950	48.3	.690
BEAM 426					
0	20.73	35	24	59.3	0.015
1000	50.73	98	75	56.6	.040
2000	80.73	153	121	56.0	.065
2500	95.73	186	152	55.0	.075
3000	110.73	226	191	54.2	.090
3500	125.73	263	231	53.2	.105
4000	140.73	304	285	51.7	.125
4500	155.73	362	378	48.9	.155
5000	170.73	433	525	45.2	.195
5500	185.73	513	723	41.5	.245
6000	200.73	579	889	39.5	.295
6460	214.53	.....	1161	.....	.....
5000	170.73	655	1096	27.9	.375
BEAM 496					
0	21.96	35	24	59.3	0.015
1000	51.96	91	58	61.2	.030
2000	81.96	145	91	61.4	.050
3000	111.96	205	130	61.2	.070
4000	141.96	265	169	61.0	.090
5000	171.96	321	210	60.4	.110
6000	201.96	382	260	59.5	.135
7000	231.96	448	316	58.7	.165
8000	261.96	520	383	57.6	.195
9000	291.96	589	453	56.5	.225
10 000	321.96	665	526	55.8	.255
11 000	351.96	741	603	55.1	.290
12 000	381.96	828	691	54.5	.325
13 000	411.96	908	773	54.0	.360
14 000	441.96	1004	862	53.8	.400
15 000	501.96	1190	1031	53.6	.475
17 000	531.96	1284	1120	53.6	.515
18 000	561.96	1392	1217	53.4	.560
19 000	591.96	1493	1320	53.1	.605
19 520	607.56	.....	1443	.....	.650
19 700	612.96	.....	1579	.....	.690
17 500	546.96	(1833)	2340	43.9	.745
BEAM 427					
0	20.52	39	27	59.3	0.015
1000	50.52	97	72	57.5	.040
1500	65.52	127	97	56.7	.050
2000	80.52	158	123	56.2	.065
2500	95.52	191	154	55.4	.078
3000	110.52	226	190	54.3	.095
3500	125.52	262	227	53.6	.110
4000	140.52	314	291	51.9	.135
4500	155.52	378	388	49.4	.160
5000	170.52	465	556	45.5	.210
5500	185.52	539	670	44.6	.260
6000	200.52	609	802	43.1	.305
6500	215.52	680	926	42.4	.385
4700	161.52	703	1800	28.1	.410
BEAM 497					
0	21.55	34	15	69.7	0.015
1000	51.55	91	53	63.2	.035
2000	81.55	141	85	62.4	.055
3000	111.55	199	121	62.2	.075
4000	141.55	251	152	62.3	.095
5000	171.55	309	198	61.0	.115
6000	201.55	373	246	60.3	.140
7000	231.55	442	304	59.3	.170
8000	261.55	512	362	58.6	.195
9000	291.55	586	427	57.8	.225
10 000	321.55	667	497	57.3	.260
11 000	351.55	750	568	56.9	.290
12 000	381.55	835	641	56.6	.320
13 000	411.55	921	715	56.3	.360
14 000	441.55	1010	786	56.2	.395
15 000	471.55	1098	865	55.9	.430
16 000	501.55	1196	942	55.9	.470
17 000	531.55	1286	1015	55.9	.510
18 000	561.55	1400	1109	55.8	.555
19 000	591.55	1499	1191	55.7	.595
20 000	621.55	1655	1385	54.4	.690
BEAM 428					
0	20.93	37	26	58.8	0.015
1000	50.93	95	68	58.3	.035
1500	65.93	129	94	57.9	.050
2000	80.93	156	118	56.9	.060
2500	95.93	190	145	56.7	.070
3000	110.93	222	178	55.5	.085
3500	125.93	262	217	54.7	.100
4000	140.93	314	284	52.5	.125
4500	155.93	375	368	50.5	.165
5000	170.93	442	494	47.2	.190
5500	185.93	514	639	44.6	.235
6000	200.93	586	809	42.0	.285
6400	212.93	.....	949	.....	.....
4800	164.93	1053	921	53.3	.430

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 438					
0	19.90	41	27	60.5	0.015
1000	49.90	103	70	59.4	.040
2000	79.90	166	115	59.1	.060
2500	94.90	202	144	58.4	.080
3100	112.90	247	178	58.1	.090
3500	124.90	277	207	57.3	.105
4000	139.90	322	243	57.0	.120
4500	154.90	366	289	55.9	.140
5000	169.90	419	349	54.6	.160
5500	184.90	476	417	53.3	.185
6000	199.90	530	489	52.0	.210
7000	229.90	652	692	48.5	.275
8000	259.90	775	904	46.2	.350
9000	289.90	901	1125	44.5	.425
9500	304.90	.....	1325	.....	.....
8000	259.90	1019	1860	35.4	.510
BEAM 439					
0	20.52	39	27	59.3	0.015
1000	50.52	97	72	57.5	.035
2000	80.52	158	115	57.8	.055
2500	95.52	187	138	57.6	.070
3000	110.52	222	164	57.5	.085
4000	140.52	289	222	56.5	.110
4500	155.52	333	267	55.5	.130
5000	170.52	379	326	53.8	.150
6000	200.52	483	463	51.1	.195
7000	230.52	600	648	48.1	.260
8000	260.52	709	836	45.9	.325
9000	290.52	816	1009	44.7	.390
9930	318.42	.....	1174	.....	.....
7400	242.52	744	933	44.4	.475
BEAM 440					
0	20.52	37	26	58.8	0.015
1000	50.52	99	70	58.7	.040
2000	80.52	156	115	57.5	.060
3000	110.52	217	164	57.0	.085
3500	125.52	253	195	56.5	.100
4000	140.52	289	224	56.3	.115
4500	155.52	331	265	55.5	.135
5000	170.52	377	323	53.9	.155
6000	200.52	482	474	50.4	.210
7000	230.52	600	667	47.4	.270
8000	260.62	710	863	45.1	.340
9000	290.52	813	1034	44.0	.410
9850	316.02	.....	1183	.....	.....
7900	257.52	936	1879	33.2	.500

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 450					
0	20.52	39	24	62.0	0.015
1000	50.52	99	62	61.5	.035
2000	80.52	163	103	61.3	.060
3000	110.52	229	144	61.2	.080
4000	140.52	295	197	59.9	.105
5000	170.52	370	270	57.8	.135
6000	200.52	463	373	55.4	.175
7000	230.52	570	504	53.1	.220
8000	260.52	678	648	51.1	.270
9000	290.52	785	793	49.7	.320
10 000	320.52	903	957	48.5	.380
11 000	350.52	1010	1104	47.8	.440
12 000	380.52	1122	1272	46.9	.500
10 500	335.52	1283	2079	38.2	.570
BEAM 451					
0	20.52	42	21	66.7	0.015
1000	50.52	102	60	63.0	.035
2000	80.52	167	99	62.8	.055
3000	110.52	231	147	61.1	.080
4000	140.52	300	200	60.0	.105
5000	170.52	376	272	58.1	.135
6000	200.52	466	369	55.8	.170
7000	230.52	566	497	53.3	.215
8000	260.52	669	646	50.9	.265
9000	290.52	775	798	49.3	.320
10 000	320.52	878	961	47.7	.375
11 000	350.52	987	1120	46.9	.430
12 000	380.52	.....	1297	.....	.....
10 300	329.52	1134	1834	38.2	.510
BEAM 452					
0	20.31	37	24	60.7	0.010
1000	50.31	100	60	62.5	.030
2000	80.31	164	108	60.2	.050
3000	110.31	228	152	60.0	.080
4000	140.31	299	207	59.1	.100
5000	170.31	369	277	57.1	.130
6000	200.31	451	368	55.1	.170
7000	230.31	547	479	53.3	.210
8000	260.31	648	615	51.3	.265
9000	290.31	747	750	49.9	.315
10 000	320.31	848	894	48.7	.370
11 000	350.31	955	1039	47.9	.425
12 000	380.31	1079	1227	46.8	.505
10 900	347.31	1216	1991	37.9	.570

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 462					
0	21.95	42	15	73.3	0.015
1000	51.95	84	43	66.3	.035
2000	81.95	163	81	66.8	.060
3000	111.95	219	122	64.2	.080
4000	141.95	275	182	60.2	.110
5000	171.95	340	251	57.6	.140
6000	201.95	405	326	55.4	.170
7000	231.95	489	423	53.7	.210
8000	261.95	603	538	52.9	.255
9000	291.95	684	653	51.2	.300
10 000	321.95	775	793	49.4	.355
11 000	351.95	877	928	48.6	.405
12 000	381.95	971	1053	48.0	.455
13 000	411.95	1065	1186	47.3	.510
13 900	438.95	.....	.....	.....	.....
11 500	366.95	1059	1261	45.6	.600
BEAM 463					
0	20.73	37	29	56.3	0.010
1000	50.73	95	75	56.0	.030
2000	80.73	152	123	55.2	.055
3000	110.73	212	171	55.4	.075
4000	140.73	281	219	56.2	.105
5000	170.73	344	272	55.8	.130
6000	200.73	424	347	55.0	.165
7000	230.73	503	439	53.4	.200
8000	260.73	596	561	51.5	.245
9000	290.73	691	696	49.8	.295
10 000	320.73	787	824	48.7	.345
11 000	350.73	886	959	48.0	.395
12 000	380.73	989	1089	47.6	.450
13 000	410.73	1095	1226	47.2	.510
13 350	421.23	.....	1303	.....	.....
11 500	365.73	1116	1169	48.8	.575
BEAM 464					
0	20.52	39	27	59.3	0.010
1000	50.52	100	65	60.7	.030
2000	80.52	162	106	60.5	.055
3000	110.52	226	152	59.8	.075
4000	140.52	295	207	58.8	.110
5000	170.52	374	272	57.9	.135
6000	200.52	452	350	56.4	.180
7000	230.52	560	460	54.9	.220
8000	260.52	667	579	53.5	.265
9000	290.52	758	699	52.0	.315
10 000	320.52	857	824	51.0	.360
11 000	350.52	964	962	50.1	.415
12 000	380.52	1065	1087	49.5	.470
13 000	410.52	1187	1238	49.0	.535
13 250	418.02	.....	1379	.....	.....
11 500	365.52	1215	1262	49.0	.630

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 474					
0	22.16	43	20	67.2	0.015
1000	52.16	100	56	64.1	.045
2000	82.16	164	93	63.7	.065
3000	112.16	226	131	63.4	.085
4000	142.16	296	181	62.0	.115
5000	172.16	373	241	60.7	.145
6000	202.16	457	319	58.9	.180
7000	232.16	552	418	56.9	.220
8000	262.16	650	527	55.2	.260
9000	292.16	749	633	54.2	.305
10 000	322.16	851	760	52.9	.350
11 000	352.16	956	868	52.4	.395
12 000	382.16	1064	997	51.6	.450
13 000	412.16	1179	1150	50.6	.505
14 000	442.16	1353	1370	49.7	.580
14 480	456.56	.....	.....	.....	.....
13 100	415.16	1424	1883	43.1	.650
BEAM 475					
0	21.14	39	24	62.0	0.015
1000	51.14	89	58	60.6	.035
2000	81.14	142	97	59.4	.055
3000	111.14	203	142	58.9	.075
4000	141.14	260	185	58.5	.095
5000	171.14	320	241	57.0	.125
6000	201.14	384	301	56.1	.150
7200	237.14	480	397	54.7	.190
8000	261.14	548	472	53.7	.225
9000	291.14	631	571	52.5	.265
10 000	321.14	733	684	51.7	.315
11 000	351.14	818	785	51.0	.355
12 000	381.14	915	896	50.5	.405
13 000	411.14	1010	1007	50.1	.450
14 000	441.14	1110	1121	49.7	.505
15 000	471.14	1217	1246	49.4	.565
15 250	478.64	.....	1285	.....	.....
13 900	438.14	1208	1200	50.1	.620
BEAM 476					
0	20.73	42	26	62.0	0.015
1000	50.73	104	65	61.6	.040
2000	80.73	168	106	61.3	.060
3000	110.73	231	150	60.6	.085
4000	140.73	302	200	60.2	.115
5000	170.73	374	258	59.2	.140
6000	200.73	457	337	57.5	.175
7000	230.73	550	431	56.1	.215
8000	260.73	657	538	55.0	.260
9000	290.73	755	658	53.4	.305
10 000	320.73	872	802	52.1	.355
11 000	350.73	973	916	51.5	.405
12 000	380.73	1085	1044	50.6	.455
13 000	410.73	1223	1215	50.2	.515
14 000	440.73	1374	1462	48.4	.585
14 240	447.93	.....	1668	.....	.....
13 050	412.23	1507	2296	40.9	.695

Appendix II—Log Sheets of Concrete Beams—Continued

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 486					
0	21.95	34	34	60.4	0.010
1000	51.95	93	85	62.6	.030
2000	81.95	149	144	61.1	.055
3000	111.95	216	202	62.0	.080
4000	141.95	281	270	61.2	.100
5000	171.95	352	335	61.5	.125
6000	201.95	431	421	60.7	.155
7000	231.95	514	518	59.8	.185
8000	261.95	603	626	58.9	.220
9000	291.95	699	740	58.3	.260
10 000	321.95	796	853	57.9	.300
11 000	351.95	903	978	57.6	.345
12 000	381.95	1010	1108	57.2	.385
13 000	411.95	1122	1241	57.0	.430
14 000	441.95	1229	1368	56.8	.480
15 000	471.95	1347	1501	56.8	.525
16 000	501.95	1524	1730	56.2	.595
17 000	531.95	1677	2222	51.6	.675
15 500	486.95	1883	2949	46.8	.720
BEAM 487					
0	21.14	37	22	62.7	0.015
1000	51.14	91	58	61.2	.030
2100	84.14	150	94	61.5	.055
3000	111.14	202	132	60.4	.075
4000	141.14	260	171	60.3	.095
5000	171.14	319	214	59.8	.115
6000	201.14	387	265	59.3	.145
7000	231.14	461	330	58.3	.170
8000	261.14	538	409	56.8	.205
9000	291.14	619	484	56.1	.240
10 000	321.14	714	576	55.4	.275
11 000	351.14	792	656	54.7	.310
12 000	381.14	889	752	54.2	.350
13 000	411.14	970	836	53.7	.390
14 000	441.14	1079	932	53.6	.435
15 000	471.14	1151	1015	53.1	470
16 000	501.14	1242	1103	53.0	.520
17 000	531.14	1360	1207	53.0	.570
18 000	561.14	1456	1350	51.9	.620
15 600	489.14	1400	1299	51.9	.680
BEAM 488					
0	21.14	35	21	62.4	0.015
1000	51.14	92	55	62.7	.035
2000	81.14	155	96	61.7	.055
3000	111.14	210	132	61.4	.075
4000	141.14	274	176	60.8	.100
5000	171.14	332	221	60.0	.120
6000	201.14	402	280	59.0	.145
7000	231.14	478	349	57.8	.175
8000	261.14	550	424	56.5	.210
9000	291.14	639	515	55.4	.245
10 000	321.14	721	607	54.3	.285
11 000	351.14	808	696	53.7	.325
12 000	381.14	898	785	53.4	.365
13 000	411.14	998	877	53.2	.405
14 000	441.14	1096	971	53.0	.450
15 000	471.14	1200	1070	52.9	.490
16 000	501.14	1300	1174	52.5	.535
17 000	531.14	1422	1320	51.9	.595
17 850	556.64	.....	1603	.....	.....
15 500	486.14	1632	2179	42.8	.685

Applied Load, lbs.	$\frac{M}{bd^2}$ lbs. per sq. in.	Deformation, millionths of inch per inch		K, per cent	Deflection, inches
		Upper Fiber	Steel Fiber		
BEAM 498					
0	21.34	39	22	64.0	0.015
1000	51.34	97	55	63.7	.035
2000	81.34	152	92	62.3	.055
3000	111.34	210	128	62.1	.075
4100	144.34	277	169	62.1	.095
5000	171.34	336	207	61.9	.120
6000	201.34	404	255	61.3	.145
7000	231.34	481	311	60.7	.170
8000	261.34	578	379	60.4	.205
9000	291.34	666	462	59.1	.245
10 000	321.34	756	545	58.1	.275
11 000	351.34	842	622	57.5	.310
12 000	381.34	924	704	56.8	.355
13 000	411.34	1026	790	56.5	.385
14 000	441.34	1119	879	56.0	.425
15 000	471.34	1231	976	55.8	.470
16 000	501.34	1324	1058	55.6	.505
17 000	531.34	1445	1147	55.7	.555
18 000	561.34	1590	1256	55.9	.610
19 000	591.34	1747	1479	54.1	.675
19 250	598.84	.....	1665	.....	.....
17 400	543.34	1782	1576	53.1	.795
BEAM 499					
0	23.19	44	15	74.4	0.010
1000	53.19	94	47	66.7	.030
2000	83.19	149	78	65.7	.050
3100	116.19	204	113	64.4	.070
4000	143.19	266	146	64.5	.090
5100	176.19	335	192	63.6	.115
6000	203.19	393	231	63.0	.140
7000	233.19	465	292	61.4	.165
8000	263.19	533	359	59.8	.195
9000	293.19	608	433	58.4	.225
10 000	323.19	682	503	57.6	.255
11 000	353.19	768	571	57.4	.290
12 000	383.19	848	669	55.9	.325
13 000	413.19	928	760	55.0	.365
14 000	443.19	1000	848	54.1	.400
15 000	473.19	1110	922	54.6	.435
16 000	503.19	1209	1002	54.7	.480
17 000	533.19	1311	1096	54.5	.520
18 000	563.19	1426	1210	54.1	.570
19 000	593.19	1584	1445	52.3	.630
19 800	617.19	.....	.....	.....	.....
17 500	548.19	1797	2289	44.0	.725
BEAM 500					
0	21.34	39	19	67.2	0.015
1000	51.34	102	53	65.7	.030
2000	81.34	154	85	64.4	.055
3100	114.34	215	126	63.1	.075
4000	141.34	265	166	61.4	.095
5000	171.34	333	210	61.3	.120
6000	201.34	402	255	61.2	.140
7000	231.34	462	306	60.2	.170
8000	261.34	537	371	59.2	.200
9000	291.34	606	438	58.1	.230
10 000	321.34	682	509	57.2	.260
11 000	351.34	771	595	56.5	.300
12 000	381.34	860	672	56.1	.335
13 000	411.34	950	754	55.8	.370
14 000	441.34	1037	832	55.5	.405
15 000	471.34	1120	908	55.2	.445
16 000	501.34	1222	993	55.2	.485
17 000	531.34	1320	1089	54.8	.525
18 000	561.34	1428	1198	54.4	.570
19 000	591.34	1577	1385	53.2	.635
19 760	614.14	.....	1658	.....	.....
17 900	558.34	2001	2600	43.5	.805

Appendix III—Additional Beam Data

1:2:4 GRANITE CONCRETE BEAMS

No. of Beam	Cross Section	First Crack	Crack of Failure	No. of Beam	Cross Section	First Crack	Crack of Failure
	Inches	Ft in	Ft in		Inches	Ft in	Ft in
162	8.00x11.00	0 8	1 2	...	.....	.....	.....
163	8.06x11.19	1 6	0 6	169	8.00x11.13	.....	2 6
164	8.06x11.00	0 4	0 4	170	8.06x11.13	.....	1 6
174	8.00x10.88	0 3	0 6	180	8.00x11.13	.....	0 4
175	8.00x10.88	0 6	1 6	181	8.06x11.06	.....	1 10
176	7.94x10.94	0 8	0 6	182	8.06x11.06	.....	1 6
186	7.94x11.25	1 0	2 0	192	8.00x11.00	.....	1 2
187	8.00x11.00	0 4	0 10	193	8.00x10.94	.....	0 6
188	8.06x11.19	0 9	1 0	194	8.06x11.19	.....	1 2
198	8.00x11.06	0 6	1 0	204	8.00x11.19	.....	0 10
199	8.00x11.00	0 0	1 3	205	8.06x11.06	.....	0 10
200	8.00x11.19	.....	0 10	206	8.06x11.06	.....	0 11
210	8.00x11.06	0 10	0 6	216	8.06x11.00	.....	0 5
211	8.00x11.25	0 5	1 10	217	8.06x11.13	.....	0 11
212	8.00x10.94	0 6	0 0	218	8.00x11.06	.....	0 10
222	8.00x11.00	0 2	0 0	231	8.00x11.13	.....	0 7
223	8.00x11.06	1 1	0 1	232	8.00x11.19	.....	0 5
224	8.00x11.06	.....	0 2	233	8.00x11.00	.....	0 0
237	8.00x11.00	.....	1 6	240	8.00x11.13	.....	1 5
238	8.06x10.88	0 10	1 1	...	.....	.....	.....
239	8.13x11.00	0 8	1 3	242	8.06x11.00	.....	1 0
163	8.00x11.00	0 6	0 6	171	8.00x11.25	0 1	0 1
166	8.00x11.00	0 6	0 1	172	8.06x11.00	0 0	0 0
167	8.00x11.00	0 5	1 8	173	8.06x11.13	.....	1 5
177	8.00x11.00	0 2	1 4	183	8.06x11.13	.....	1 0
178	8.13x10.94	0 0	1 3	184	8.06x11.13	.....	1 1
179	8.00x11.13	0 0	1 3	185	8.06x11.25	.....	1 4
189	8.00x11.00	0 2	0 2	195	8.06x11.13	.....	1 9
190	8.00x11.00	0 3	1 6	196	8.06x11.13	.....	1 0
191	7.94x11.06	2 0	0 2	197	8.00x11.13	.....	1 3
201	8.00x11.13	.....	0 3	207	8.00x11.13	.....	0 2
202	8.00x11.06	0 4	0 0	208	8.06x11.00	.....	0 5
203	8.00x11.00	0 5	0 5	209	8.06x11.13	.....	2 1
213	8.00x11.06	.....	2 1	219	8.06x11.19	.....	2 3
214	8.00x11.00	.....	0 11	220	8.06x11.19	.....	0 1
215	7.94x11.00	0 0	0 0	221	8.06x11.19	.....	1 2
225	8.00x11.00	.....	0 5	228	8.06x11.00	.....	0 3
226	8.00x11.13	.....	0 11	229	8.00x11.19	.....	1 2
227	8.00x11.00	0 6	1 3	230	8.06x11.16	.....	1 8
243	8.00x11.13	.....	0 0	234	8.00x11.00	.....	0 7
244	8.06x11.06	0 8	1 9	235	8.06x11.00	.....	1 7
245	8.00x11.13	.....	0 11	236	8.06x11.00	.....	1 1

Appendix III—Additional Beam Data—Continued.

1:2:4 LIMESTONE CONCRETE BEAMS

No. of Beam	Cross Section	First Crack	Crack of Failure	No. of Beam	Cross Section	First Crack	Crack of Failure
	Inches	Ft in	Ft in		Inches	Ft in	Ft in
...	.....	.....	.....	252	8.00x11.06	.....	0 4
256	8.00x11.00	.....	0 8	253	8.06x11.13	.....	0 7
257	8.00x11.06	0 7	0 7	254	8.13x11.31	.....	0 6
261	8.00x11.38	0 2	2 0	267	8.06x11.13	.....	0 6
262	8.00x11.25	0 6	1 10	268	8.06x11.19	.....	1 11
263	8.00x11.50	.....	1 0	269	8.06x11.13	.....	1 6
273	8.06x11.25	1 9	1 2	279	8.00x11.06	.....	1 7
274	8.00x11.50	1 6	1 0	280	8.06x11.13	.....	0 7
275	8.00x11.31	0 2	0 4	281	8.06x11.06	.....	0 2
285	7.94x11.25	0 8	1 7	291	8.06x11.13	.....	0 3
286	8.06x11.13	.....	1 3	292	8.06x11.13	.....	0 9
287	8.13x11.38	.....	0 2	293	8.06x11.13	.....	0 3
297	8.00x11.31	0 8	0 3	303	8.13x11.00	.....	1 2
298	8.00x11.00	.....	1 4	304	8.00x11.19	.....	0 0
299	7.94x11.38	0 6	0 0	305	8.00x11.31	.....	0 0
318	8.00x11.25	.....	0 11	315	8.06x11.13	.....	0 8
319	8.00x11.06	.....	0 0	316	8.06x11.31	.....	1 1
320	8.06x11.06	.....	0 6	317	8.06x11.19	.....	0 2
321	8.00x11.13	.....	0 7	327	8.06x11.13	0 1	0 5
322	8.06x10.94	.....	1 6	328	8.06x11.13	.....	1 11
323	7.94x11.25	.....	0 2	...	.....	.....	.....
249	8.06x11.13	.....	2 0	245	8.06x11.13	.....	1 1
250	8.06x11.13	0 2	0 2	247	8.13x11.19	.....	0 1
251	8.00x11.13	0 7	0 4	248	8.06x11.06	.....	2 1
264	8.00x11.13	.....	1 5	270	8.06x11.25	.....	0 7
265	8.00x11.13	.....	0 2	271	8.00x11.38	.....	1 3
266	8.00x11.06	.....	0 3	272	8.06x11.31	.....	0 0
276	8.00x11.00	.....	2 0	282	8.00x11.31	.....	0 7
277	8.00x11.25	0 5	0 2	283	8.06x11.31	.....	0 7
278	8.00x11.13	.....	1 10	284	7.94x11.25	.....	1 1
288	8.06x11.06	.....	1 3	294	7.94x11.38	.....	0 2
289	8.00x11.06	0 5	1 3	295	8.06x11.31	.....	0 10
290	8.00x11.19	.....	1 8	296	8.06x11.25	.....	0 5
300	8.00x11.13	.....	1 2	306	8.00x11.00	.....	0 0
301	8.00x11.19	0 9	0 2	307	8.13x11.31	1 7	0 9
302	8.00x11.00	.....	0 5	308	7.94x11.25	.....	0 2
312	8.13x10.94	.....	0 11	309	8.00x11.19	.....	1 6
313	8.00x11.13	.....	1 4	310	8.06x11.00	1 7	1 5
314	8.06x11.06	.....	1 5	311	8.13x11.06	.....	0 4
324	8.00x11.06	.....	1 2	330	8.06x11.19	2 0	1 7
325	8.06x11.25	.....	0 7	331	8.06x11.00	.....	1 1
326	8.00x11.06	.....	0 8	332	7.94x11.06	.....	0 10

Appendix III—Additional Beam Data—Continued.

1:2:4 GRAVEL CONCRETE BEAMS

No. of Beam	Cross Section	First Crack	Crack of Failure	No. of Beam	Cross Section	First Crack	Crack of Failure
	Inches	Ft in	Ft in		Inches	Ft in	Ft in
333	8.00x10.94	0 5	1 2	339	8.06x11.06	0 6	0 6
334	8.13x10.94	0 4	0 1	340	8.06x11.19	.....	0 10
335	8.06x11.19	1 6	1 6	341	8.06x11.00	.....	1 8
345	8.00x11.00	.....	1 2	351	8.06x11.13	.....	0 5
346	8.00x11.00	.....	0 8	352	8.06x11.25	.....	1 4
347	8.00x11.00	.....	0 0	353	8.06x11.06	.....	1 3
357	8.00x11.00	.....	1 0	363	8.06x11.13	0 9	0 9
358	8.00x10.94	0 0	0 5	364	8.06x11.25	.....	1 1
359	8.00x11.13	.....	1 6	365	8.06x11.06	.....	0 6
369	8.06x11.00	0 8	1 2	375	8.00x11.19	1 7	1 5
370	8.00x11.00	0 4	0 0	376	8.06x11.19	.....	1 4
371	7.94x10.81	.....	1 10	377	8.06x11.06	.....	1 5
381	7.88x11.00	.....	0 7	387	8.06x11.00	.....	0 3
382	8.06x11.00	0 8	1 1	388	8.00x11.25	.....	0 6
383	8.00x11.06	.....	0 10	389	8.06x11.00	.....	1 2
393	8.00x10.94	.....	1 6	399	8.06x11.00	.....	0 0
394	8.00x10.88	0 5	1 6	400	8.00x11.31	.....	0 8
395	8.00x11.13	.....	0 5	401	8.00x11.06	0 0	1 3
405	7.94x10.94	0 4	0 8	...	.....	.....	.....
406	8.00x10.94	1 9	0 2	412	8.06x11.13	0 7	1 3
407	8.00x10.88	.....	0 3	413	8.06x11.06	.....	2 0
336	8.00x11.13	1 8	1 2	342	7.94x11.13	0 6	0 6
337	8.06x11.19	0 7	1 6	343	8.06x10.94	.....	1 5
338	8.06x11.06	1 8	0 2	344	8.06x10.88	.....	1 3
348	8.00x11.00	.....	0 11	354	8.00x11.00	.....	0 0
349	8.00x11.19	.....	0 5	355	8.06x11.00	.....	0 5
350	8.00x11.00	.....	0 11	356	8.00x11.06	.....	1 2
360	8.00x11.06	.....	0 6	366	7.94x11.13	.....	0 1
361	8.06x11.25	1 10	1 1	367	8.06x11.06	.....	1 1
362	8.00x11.00	1 11	1 2	368	8.06x10.94	.....	0 10
372	8.00x11.06	.....	0 5	378	8.00x10.88	.....	0 3
373	8.00x11.13	.....	1 0	379	8.00x11.00	.....	1 3
374	8.00x11.06	.....	0 3	380	7.94x11.06	.....	0 4
384	8.06x11.06	.....	0 2	390	8.06x11.00	.....	0 9
385	8.00x11.06	.....	0 7	391	8.06x11.13	.....	0 8
386	8.00x11.00	0 3	0 8	392	8.06x10.94	.....	0 8
396	8.00x11.06	1 0	0 0	402	8.06x11.00	.....	0 6
397	8.00x11.13	.....	0 3	403	8.06x11.00	.....	1 5
398	8.06x10.94	.....	0 5	404	8.00x11.06	0 0	0 7
408	8.00x11.06	.....	1 2	414	8.00x10.94	.....	0 6
409	8.00x11.13	1 9	0 8	415	8.00x11.00	.....	0 11
410	8.00x11.13	.....	0 7	416	8.06x10.88	0 6	0 5

Appendix III—Additional Beam Data—Continued

1:2:4 CINDER CONCRETE BEAMS

No. of Beam	Cross Section	First Crack	Crack of Failure	No. of Beam	Cross Section	First Crack	Crack of Failure
	Inches	Ft in	Ft in		Inches	Ft in	Ft in
417	8.00x10.94	0 7	1 4	423	8.06x11.06	0 0	0 10
418	8.00x11.00	.....	0 10	424	8.00x11.13	.....	1 8
419	8.00x11.00	.....	1 7	425	8.06x11.06	.....	1 10
429	8.00x11.00	0 10	0 0	435	8.00x11.00	0 6	0 7
430	8.00x10.94	0 9	0 5	436	8.06x11.19	.....	1 9
431	8.00x10.88	1 6	1 6	437	8.00x11.13	.....	0 5
441	8.00x10.81	1 7	1 2	447	8.06x11.13	.....	0 9
442	8.00x10.94	.....	1 0	448	8.00x11.31	.....	1 5
443	8.00x11.00	.....	1 2	449	8.06x11.13	.....	0 7
453	7.88x10.94	.....	0 3	459	8.00x11.19	.....	0 3
454	8.00x11.00	.....	1 4	460	8.06x11.19	.....	0 7
455	8.00x10.94	.....	0 5	461	8.00x11.00	.....	1 10
465	8.00x10.88	.....	0 3	471	8.00x11.13	.....	0 10
466	8.00x11.06	.....	0 6	472	8.00x11.19	.....	0 3
467	7.94x10.94	.....	0 2	473	8.00x11.06	.....	0 5
477	7.94x11.00	.....	1 0	483	8.06x11.13	.....	0 2
478	8.00x11.06	.....	1 10	484	8.00x11.25	.....	2 0
479	8.00x11.00	.....	1 0	485	8.06x11.06	.....	0 11
489	8.00x10.88	0 7	0 9	495	8.06x11.06	1 10	1 2
490	8.00x11.13	.....	0 6	496	8.00x11.19	.....	0 5
491	7.94x11.44	.....	0 3	497	8.06x11.06	.....	1 3
420	7.94x11.06	0 3	0 3	426	7.94x11.00	.....	0 10
421	8.00x11.13	.....	0 2	427	7.94x10.94	.....	0 4
422	8.00x11.06	.....	0 2	428	8.00x10.88	0 6	1 3
432	8.00x11.06	.....	1 10	438	8.00x10.88	.....	0 1
433	8.00x11.19	0 2	1 11	439	8.00x10.88	.....	1 6
434	8.06x11.13	.....	0 11	440	8.06x10.88	.....	0 7
444	8.06x11.06	.....	0 8	450	8.06x10.81	0 0	0 7
445	8.13x11.19	0 6	0 8	451	8.00x11.19	.....	0 9
446	8.00x11.13	.....	0 2	452	7.94x11.00	.....	0 6
456	8.00x11.06	.....	0 10	462	7.94x11.13	.....	1 8
457	7.94x11.19	.....	1 6	463	8.00x11.00	.....	1 3
458	8.06x11.00	.....	0 10	464	8.06x10.81	.....	1 5
468	8.00x11.00	.....	1 3	474	8.06x10.81	.....	0 5
469	8.00x11.00	.....	.....	475	8.00x11.13	.....	1 5
470	8.00x11.19	0 5	0 2	476	7.94x10.88	.....	0 3
480	8.00x11.06	1 6	0 5	486	8.00x10.81	.....	0 8
...	.....	.....	.....	487	8.00x11.19	.....	1 8
482	8.00x11.13	2 0	0 2	488	8.00x11.06	.....	0 8
492	8.00x11.06	.....	0 10	498	8.00x10.94	.....	2 0
493	8.13x11.19	1 4	1 4	499	8.06x11.00	.....	1 2
494	8.00x11.00	.....	0 0	500	7.94x11.06	.....	0 5

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No. 3

TESTS OF THE ABSORPTIVE AND PERMEABLE PROPERTIES OF PORTLAND CEMENT MORTARS AND CONCRETES

TOGETHER WITH

TESTS OF DAMP-PROOFING AND WATERPROOFING COMPOUNDS AND MATERIALS

BY

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PREFACE.

The investigations herein reported were made by the Technologic Branch of the United States Geological Survey at the Structural Materials Testing Laboratories, St. Louis, Mo., under the direction of Richard L. Humphrey.

When this work was transferred to the Bureau of Standards, July 1, 1910, the unpublished data were delivered to this Bureau.

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Fig. 1.—*General View of Permeability Laboratory.*

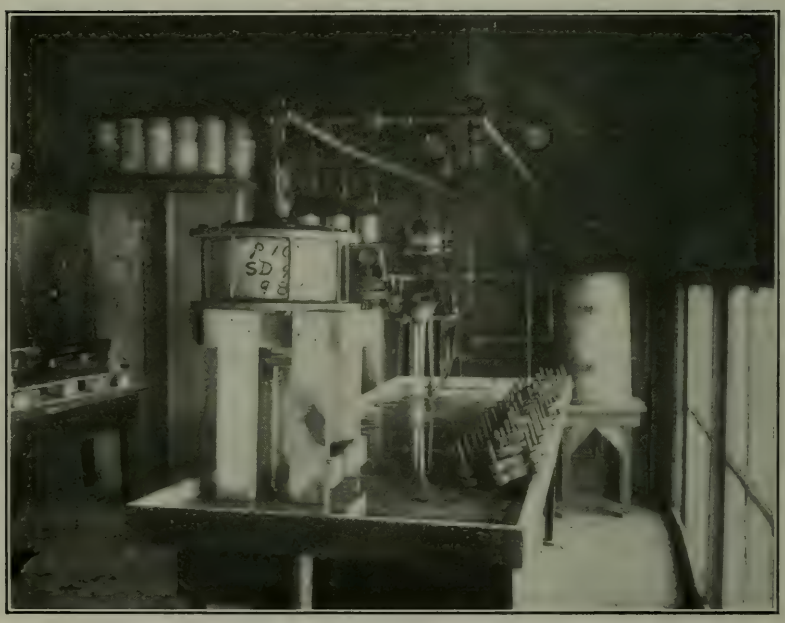

Fig. 2.—*View of Piping and Permeability Testing Apparatus.*

TESTS OF THE ABSORPTIVE AND PERMEABLE PROPERTIES OF PORTLAND CEMENT MORTARS AND CONCRETES, TOGETHER WITH TESTS OF DAMPPROOFING AND WATERPROOFING COMPOUNDS AND MATERIALS

By R. J. Wig and P. H. Bates

PART I

TESTS OF THE ABSORPTIVE AND PERMEABLE PROPERTIES OF PORTLAND CEMENT MORTARS AND CONCRETES

I. INTRODUCTION

A knowledge of the absorptive and permeable qualities of Portland cement has become imperative with its increased application, resulting from the recognition of its economy and adaptability for building and engineering construction. Intelligent and comprehensive tests for these qualities in a material so variable as concrete are difficult to execute. The constituents of concrete vary in absorptive qualities, porosity, percentage of voids, and surface qualities. These constituents may combine in numerous ways which will vary with changes in consistency, in manner of placing, in the stroke of the tamper, or the pressure of the trowel.

The investigations reported in this paper are not exhaustive. They cover some previously uninvestigated phases of this important subject and are contributory to our present meager knowledge.

The investigations are reported in two parts. Part I comprises the results of a series of tests on 11 different mortars and 23 concretes to determine their permeability at various ages, for various consistencies and thickness of test piece, and the absorption on 12 mortars at various ages and for various consistencies. Part II contains the results of a series of comparative tests of

40 compounds and several void-filling materials recommended for use or advertised as "damp-proofing" or "waterproofing" mediums, purchased privately in the open market.

All Portland cement, sand, and stone used excepting materials from the Isthmus of Panama were furnished by the following companies: Iola Portland Cement Co., Iola, Kans.; Atlas Portland Cement Co., Hannibal, Mo.; Whitehall Portland Cement Co., Cementon, Pa.; Universal Portland Cement Co., Chicago, Ill.; Edison Portland Cement Co., New Village, N. J.; Omega Portland Cement Co., Mosherville, Mich.; Old Dominion Portland Cement Co., Fordwick, Va.; Lehigh Portland Cement Co., Mitchell, Ind.; St. Louis Portland Cement Co., St. Louis, Mo.; Union Sand & Material Co., St. Louis, Mo.; American Sand & Gravel Co., Chicago, Ill.; Illinois Steel Co., Chicago, Ill.; Fruin-Bambrick Construction Co., St. Louis, Mo.

Acknowledgment is made to G. W. Riddle and C. Oliphant for their work in planning and supervising part of the first series of tests and for designing the original permeability testing apparatus and equipment. Acknowledgment is also made to R. F. Havlik for his assistance in conducting the tests.

II. PURPOSE OF TESTS

The purpose of these investigations was to determine the permeability and absorption of Portland cement mortars and concretes made with typical materials, and to determine the necessity for and the value of so-called "damp-proofing" and "waterproofing" mediums.

III. OUTLINE OF TESTS ON MORTARS AND CONCRETES

1. PERMEABILITY

Series No.	Mortar or concrete made of 1 part by volume of Portland cement to—	Consistency	Thickness of test piece in inches	Number of tests by weeks					
				1	2	4	8	13	26
1	2 parts of No. 1 sand	Quaking	1	....	....	3	3	....	3
	do	do	2	....	....	3	3	....	3
	do	do	3	....	....	3	3	....	3
	4 parts of No. 1 sand	do	1	....	....	3	3	....	3
	do	do	2	....	....	3	3	....	3
	do	do	3	....	....	3	3	....	3

I. PERMEABILITY—Continued

Series No.	Mortar or concrete made of 1 part by volume of Portland cement to—	Consistency	Thickness of test piece in inches	Number of tests by weeks					
				1	2	4	8	13	26
1	6 parts of No. 1 sand	Quaking	1			3	3		3
	do	do	2			3	3		3
	do	do	3			3	3		3
	8 parts of No. 1 sand	do	1			3	3		3
	do	do	2			3	3		3
	do	do	3			3	3		3
2	2 parts of No. 1 sand	Damp	2	3	3	3			
	4 parts of No. 1 sand	do	2	3	3	3			
	6 parts of No. 1 sand	do	2	3	3	3			
3	2 parts of No. 2 sand	Quaking	2			3	3		3
	do	do	3			3	3		3
4	2 parts of No. 1 sand and 4 parts of No. 7 stone	do	2			3	3		3
			3			3	3		3
	3 parts of No. 1 sand and 6 parts of No. 7 stone	do	2			3	3		3
			3			3	3		3
	4 parts of No. 1 sand and 8 parts of No. 7 stone	do	2			3	3		3
			3			3	3		3
6	0 part of No. 4 sand and 6 parts of No. 6 stone	do	6					1	
	½ part No. 4 sand and 5½ parts of No. 6 stone	do	6					1	
	1 part No. 4 sand and 5 parts No. 6 stone	do	6					1	
	1½ parts No. 4 sand and 4½ parts No. 6 stone	do	6					1	
	2 parts No. 4 sand and 4 parts No. 6 stone	do	6					1	
	3 parts No. 4 sand and 3 parts No. 6 stone	do	6					1	
	0 part No. 4 sand and 9 parts No. 6 stone	do	6					1	
	1 part No. 4 sand and 8 parts No. 6 stone	do	6					1	
	1½ parts No. 4 sand and 7½ parts No. 6 stone	do	6					1	
	2 parts No. 4 sand and 7 parts No. 6 stone	do	6					1	
	3 parts No. 4 sand and 6 parts No. 6 stone	do	6					1	
	4 parts No. 4 sand and 5 parts No. 6 stone	do	6					1	
7	½ part No. 5 sand and 5½ parts No. 6 stone	do	6					1	
	1 part No. 5 sand and 5 parts No. 6 stone	do	6					1	
	2 parts No. 5 sand and 4 parts No. 6 stone	do	6					1	
	3 parts No. 5 sand and 3 parts No. 6 stone	do	6					1	
	1 part No. 5 sand and 8 parts No. 6 stone	do	6					1	
	2 parts No. 5 sand and 7 parts No. 6 stone	do	6					1	
	3 parts No. 5 sand and 6 parts No. 6 stone	do	6					1	
	4 parts No. 5 sand and 5 parts No. 6 stone	do	6					1	
18	1 part No. 1 sand	do	2						
	2 parts No. 1 sand	do	2						
	3 parts No. 1 sand	do	2						
	4 parts No. 1 sand	do	2						
	5 parts No. 1 sand	do	2						
	6 parts No. 1 sand	do	2						

[1] Three test pieces made for each mixture, tested at one week and retested at succeeding periods. (Surfaces troweled.)

2. ABSORPTION

Series No.	Mortar made of 1 part by volume of Portland cement to—	Consistency	Number of tests by weeks				
			1	2	4	8	26
9	2 parts of No. 1 sand	Damp	3	3	3	3	3
	4 parts of No. 1 sand	do	3	3	3	3	3
	6 parts of No. 1 sand	do	....	....	3	3	3
	8 parts of No. 1 sand	do	....	....	3	3	3
	2 parts of No. 1 sand	Quaking	....	....	3	3	3
	4 parts of No. 1 sand	do	....	....	3	3	3
	6 parts of No. 1 sand	do	....	....	3	3	3
	8 parts of No. 1 sand	do	....	....	3	3	3
10	2 parts of No. 2 sand	Damp	....	....	3	3	3
	4 parts of No. 2 sand	do	....	....	3	3	3
	6 parts of No. 2 sand	do	....	....	3	3	3
	8 parts of No. 2 sand	do	....	....	3	3	3
	2 parts of No. 2 sand	Quaking	....	....	3	3	3
	4 parts of No. 2 sand	do	....	....	3	3	3
	6 parts of No. 2 sand	do	....	....	3	3	3
	8 parts of No. 2 sand	do	....	....	3	3	3
11	2 parts of No. 3 sand	Damp	....	....	3	3	3
	4 parts of No. 3 sand	do	....	....	3	3	3
	6 parts of No. 3 sand	do	....	....	3	3	3
	8 parts of No. 3 sand	do	....	....	3	3	3
	2 parts of No. 3 sand	Quaking	....	....	3	3	3
	4 parts of No. 3 sand	do	....	....	3	3	3
	6 parts of No. 3 sand	do	....	....	3	3	3
	8 parts of No. 3 sand	do	....	....	3	3	3

IV. EQUIPMENT AND APPARATUS

The general view of the laboratory in which these investigations were made is shown in Fig. 1, and a more detailed view of the piping and permeability testing apparatus is given in Fig. 2. A diagram of the pipe connections is shown in Fig. 3.

The apparatus for holding the test pieces for the permeability tests is shown in Fig. 4 in sections ready to assemble, and Fig. 5 is a cross-sectional view of the test piece assembled ready for testing. A, A are rubber washers of 5-inch inside diameter and 8-inch outside diameter; B, B are cast-iron top and bottom sections of the holder; C is the test piece 7½ inches in diameter and 1, 2, or 3 inches thick and is retained in corresponding short-length sections of 7½-inch diameter wrought-iron pipe as shown in Fig. 6; D is the retainer in which the water passing through the test piece is caught. In Fig. 7 is shown a large test piece, 18

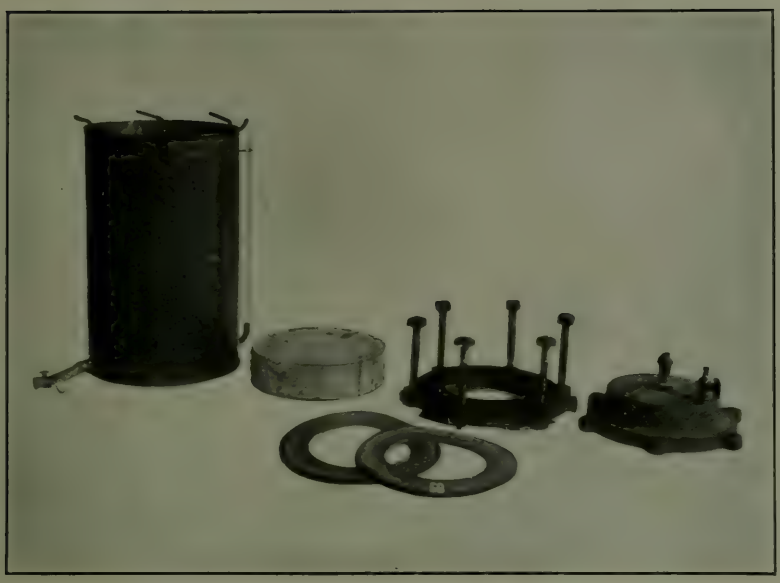

Fig. 4.—*Permeability Test Piece Holder.*

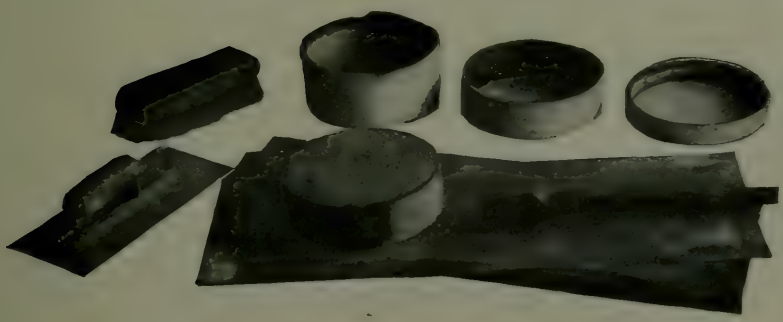

Fig. 6.—*Permeability Molds and Test Piece.*

inches in diameter and 6 inches thick with cast-iron holder and rubber washers. Concrete containing large aggregate was tested in this form.

V. TESTS OF CONSTITUENT MATERIALS

The cement used is known as typical Portland cement, and was prepared by thoroughly mixing together in a cubical mixer an

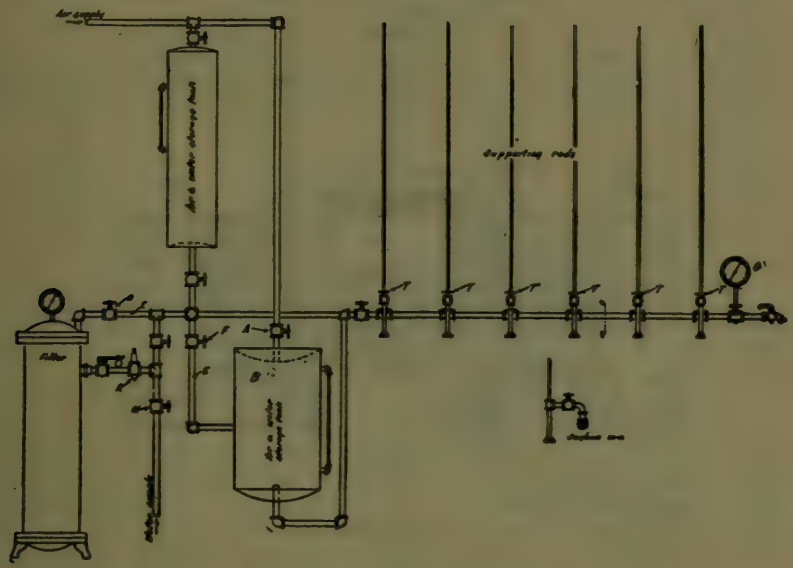

Fig. 3.—*Diagram of Pipe connections.*

equal number of sacks of nine different brands of Portland cement. Two samples were taken from each batch for making the physical tests and for chemical analysis.

The mixture was sealed in air-tight cans each of 800 pounds capacity.

1. CEMENT

The average results of chemical and physical tests are as follows:

Chemical:

Silica (SiO_2)	21.70
Alumina (Al_2O_3)	8.53
Ferric oxide (Fe_2O_3)	2.23
Lime (CaO)	62.00
Magnesia (MgO)	1.74
Sulphuric anhydride (SO_3)	1.67
Water (H_2O)	.43

Chemical—Continued.

Ignition loss	0.98
Undetermined	.94

Physical:

Residue on 100 sieve	per cent	5.1
Residue on 200 sieve	do	21.
Specific gravity		3.108
Water for normal consistency	per cent	21.4

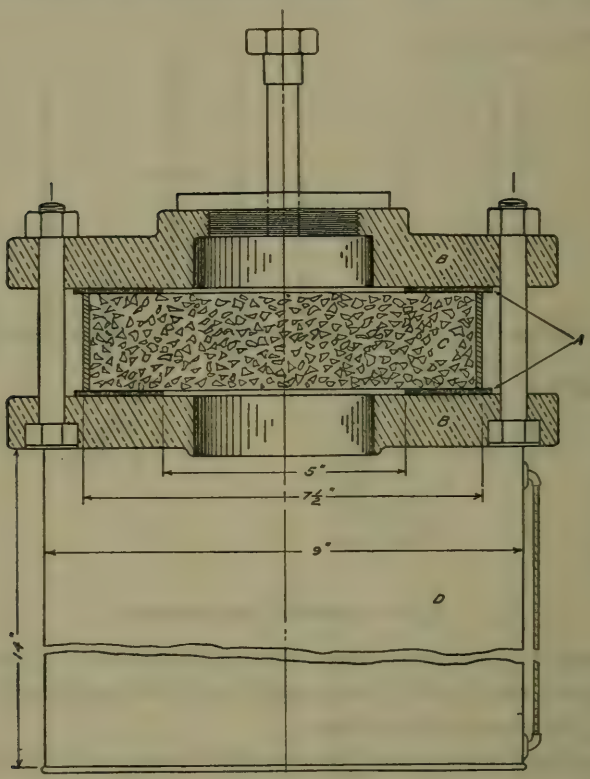

Fig. 5.—*Cross Section of Apparatus for Holding Permeability Test Pieces.*

Time of set in minutes—

Vicat—Initial	135
Final	357
Gilmore—Initial	174
Final	402

Soundness as indicated by pat test:

In air at 70° F, normal in all but 2 cases.
In water at 70° F, normal in every case.
In steam at 212° F, for 5 hours, all normal.
In water at 212° F, for 5 hours, all normal.

Strength of neat test pieces (pounds per square inch)

Age in days	Tensile	Compressive	Transverse
1	336	2 789	761
7	659	7 379	1 512
28	778	9 429	1 674
90	828	12 044	1 953
180	840	13 993	2 023

Strength of 1 : 3 standard sand mortar test pieces (pounds per square inch)

7	294	2 105	593
28	409	3 572	920
90	457	3 905	907
180	468	4 343	847

2. PHYSICAL PROPERTIES OF SANDS AND STONES

Name	Meramec River sand	Bank torpedo sand	Slag sand	Beach sand		Limestone	Limestone
Register No.	1	2	3	4	5	6	7
Location	Drake, Mo.	Chicago, Ill.		Nombre de Dios, Panama.	Quango Beach, Panama.	Porto Bello, Panama.	St. Louis, Mo.
Specific gravity	2.597	.....	2.440	2.727	2.505	2.594	2.489
Weight in lbs. per cu. ft.	100.6	119.9	82.3	105.6	91.0	102.1	97.7
Percentage of voids	37.9	26.9	45.3	37.92	41.72	35.90	37.1
Fineness in percentage passing sieve—							
200	0.20	0.70	0.60	.....	.....	.....	2.96
100	1.30	1.30	1.40	1.50	1.50	1.90	3.48
80	3.60	2.10	2.10	10.00	10.00	3.40	3.70
50	13.90	7.30	5.80	18.00	31.50	4.34	4.18
40	37.00	14.50	11.40	28.00	46.50	4.90	4.68
30	64.00	29.80	24.00	45.00	62.00	5.85	5.23
20	81.50	45.20	45.40	64.00	72.00	7.00	6.21
10	97.00	72.10	84.30	97.00	86.00	10.00	10.09
¼	100.00	100.00	100.00	100.00	100.00	19.00	28.71
½	.....	.....	.....	.....	.....	30.50	60.86
¾	.....	.....	.....	.....	.....	47.00	95.04
1	.....	.....	.....	.....	.....	59.00	99.37
1¼	.....	.....	.....	.....	.....	81.00	100.00
1½	.....	.....	.....	.....	.....	89.00	.....
1¾	.....	.....	.....	.....	.....	96.50	.....
2	.....	.....	.....	.....	.....	98.00	.....
2½	.....	.....	.....	.....	.....	100.00	.....

VI. DESCRIPTION OF TESTS

1. PROPORTIONS

The proportions of the constituent materials of the mortar or concrete were assumed according to volume measure, but since the actual quantity of sand or stone in a given volume is largely dependent upon its relative dryness and the method employed in filling the measure, it was deemed advisable to convert volume measurements into weight measurements.

The weight of the cement was assumed as 100 pounds per cubic foot, and the weight per cubic foot of the sand and stone used, reported on page 7, was determined in accordance with the methods given on page 26 of Bulletin 329, United States Geological Survey. The sand was taken directly from the storage bin without previous drying and contained an appreciable amount of moisture, for which a correction was made in the volume weights. A part of this weight was made up of moisture present in the sand and stone. This determination of the moisture was made each day, using a 300-gram sample from the material taken from the bin. The weight of the sand or stone required was increased by the percentage of moisture found to be present and the quantity of water to be added to produce a mixture of normal consistency was correspondingly decreased.

2. CONSISTENCY

The two consistencies used, designated as "damp" and "quaking," were determined for each kind of mixture previous to making the test pieces, and are defined as follows:

A mortar or concrete of damp consistency contains only sufficient water to hold the particles together when made into a ball in the hands and the ball held between the thumb and finger. The water could not be brought to the surface by troweling. This quantity of water was recorded as a percentage of the total weight of the dry material and was used for making all test pieces of the same materials and proportions.

A mortar or concrete of quaking consistency contained all the water it would hold and permit of molding into a ball in the hands and holding between the thumb and finger. Water could easily be brought to the surface under the pressure of the trowel.

Fig. 7.—*Large Permeability Test Piece and Holder.*

Fig. 8.—*Cube and Briquet Molds.*

3. MIXING

The materials were weighed. The stone and sand were spread on the mixing table and the cement spread evenly on top, and the materials were mixed thoroughly dry by turning with the trowel for about two minutes. A crater was then made in the center, into which the proper percentage of clean water was poured; the materials on the outer edge being turned into the crater with the aid of a trowel. As soon as the water was absorbed the materials were kneaded for about two minutes. The materials for the 18-inch diameter by 6-inch thick test pieces were mixed on a nonabsorbent floor with a shovel in a similar manner.

4. MOLDING

Three test pieces were molded from each batch. The iron molds in which the permeability test pieces were molded are shown in Fig. 6 with the pallet board which has a sheet-zinc top. These molds were cut from wrought-iron well casing, 7½ inches in diameter, in sections 1, 2, and 3 inches in length. The inner surfaces of the molds were wetted and placed on the pallet board and the mortar or concrete pressed firmly into the molds with the fingers, care being taken to exert a uniform pressure in molding all test pieces. The material was piled up and compacted above the level of the molds and struck off with the edge of a trowel. The 1-inch molds were filled in one, the 2-inch in two, and 3-inch in three operations. The test pieces of Series 8 were molded as described on page 52, Part II, of this paper, excepting surfaces were troweled hard and not brushed with wire brush.

The molds for the 18-inch diameter test pieces were filled about one-fourth full and tamped around six times with a 13-pound peen-shaped tamper, care being taken to cover the entire surface. This operation was repeated until the mold was filled, when it was leveled off with a plasterer's trowel. Twenty-four hours after molding, the top and bottom surfaces of these test pieces were brushed with a wire brush, which removed any neat cement which may have been drawn to the surface in molding, thus making the entire test piece approximately homogeneous.

11751°—15——2

The absorption test pieces were made in 3-gang 2-inch cube molds on glass plates. (Fig. 8.) The materials were pressed into the mold with the fingers and both top and bottom surfaces were smoothed with a trowel.

5. STORAGE

All test pieces were placed in a moist closet for the first 24 hours, after which the permeability test pieces were removed from the pallet board and stored on shelves in the damp room shown in Fig. 9 until tested. The iron molds were allowed to remain on the permeability test pieces until the testing was completed.

The molds were removed from the absorption test pieces 24 hours after molding, and the latter were then taken to the damp room and stored on shelves until tested.

All test pieces in the damp room were sprayed with water at regular intervals three times each 24 hours.

6. TESTING

Permeability test pieces were brought from the damp room on the morning of the day they were to be tested and both surfaces were brushed with a stiff wire brush in an attempt to remove any surface "skin" of cement drawn to the surface in molding. This was accomplished only with difficulty in some cases. They were then placed in the test-piece holders as shown in Fig. 5, page 12, a $\frac{3}{16}$-inch soft rubber gasket being placed between each of the cast-iron plates and the test piece. The two sections of the holder were drawn tightly together with the bolts as shown, care being taken to draw up evenly on opposite sides. The holder with test piece was then connected to the pipe rack by means of a union, as shown in Fig. 2. After similarly assembling and connecting all of the test pieces, the valve M (Fig. 3) was opened, admitting water through the regulating valve R to the filter, thence through the pipe E to tank B. When the water reached a mark as indicated on the gauge it was shut off and air admitted through the valve A, which was closed when the pressure gauge G registered 20 pounds (9.1 kilograms). The pet cocks on the test-piece holders were opened and valve T slowly opened until all air was exhausted from the chamber on the upper surface of the test piece and water flowed

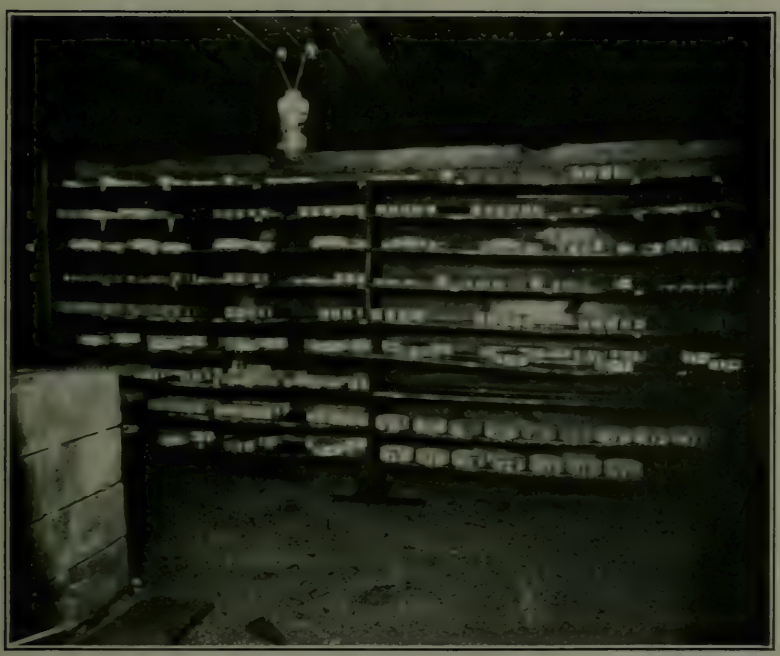

Fig. 9.—*Storage of Test Pieces.*

freely from the pet cock. The pet cocks were then closed and the valve T opened full, thus exposing 126.68 square centimeters (19.64 square inches) of the upper surface of the test piece to the full water pressure of 20 pounds per square inch (1.4 kilograms per square centimeter), which was arbitrarily chosen for all permeability tests and is equivalent to a hydrostatic head of 46.2 feet. As the flow started the regulating valve R was set and the air cushion in the tank B assisted in steadying the pressure and preventing variation. The flow was caught for a period of one minute in a glass graduate or large calibrated retainer (see Fig. 4), dependent upon the quantity passing, at the end of the tenth, thirtieth, and sixtieth minute and each succeeding hour until the seventh when the water was turned off and the test piece removed. In some cases the test was continued for several days, a reading being taken every 24 hours, and some test pieces were subjected to a retest at a later period. The 18-inch diameter concrete permeability test pieces were tested in most cases for periods of 10, 30, 60, and 120 minutes, and 24 and 48 hour periods under the same or increased pressure.

The absorption test pieces were brought from the damp room on the day to be tested and placed in an oven where the temperature was maintained between 100° and 110° C. (212° to 230° F.). They were weighed twice daily for four or five days or until they showed no further loss in weight. They were then permitted to cool slowly in the air until the following day when they were immersed so that the top surface was 3 inches below the surface of the water. They were taken from the water, the surfaces dried with a towel and weighed; they were then replaced in water and the operation repeated daily until they showed less than one-twentieth of 1 per cent daily increase. This required from 7 to 14 days, at which time the test was considered completed.

VII. RESULTS OF TESTS

1. COMPUTATIONS

The quantity of water flowing through the permeability test pieces for one minute at each period, for which a reading was taken, was recorded.

The cubic centimeters of water passed per minute per square centimeter of surface was computed by dividing the total quantity of water that passed through the test piece in one minute by its area in square centimeters, which was 126.68 for the 7½-inch diameter test pieces, and 504.7 square centimeters for the 18-inch diameter test pieces. Only this computed result is reported in the accompanying tables and an average is taken for each three similar test pieces. Where there was no measureable drip or flow, but the surface opposite to that to which the pressure was applied continued to remain moist, showing that some moisture was penetrating, it is recorded as "moist" in the tables. Readings recorded as "zero" indicate that no moisture whatever appeared on this surface. Of course, theoretically it is possible that a very slight amount of moisture came through but evaporated so rapidly that the surface remained dry in appearance, but later tests would indicate that this was not the case.

The absorption and apparent porosity is computed from the recorded results in the following manner:

The minimum dry weight of the test piece and the maximum wet weight was recorded.

Let D equal dry weight in grams.

Let W equal wet weight in grams.

Let V equal volume of 2-inch cube in cubic centimeters.

Let A equal percentage absorption in terms of dry weight.

Let P equal percentage absorption in terms of volume, or apparent porosity.

Then $W-D$ = gain in weight or the weight of water absorbed,

and $A=\frac{W-D}{D}\times 100$ = per cent absorbed in terms of the dry weight,

and since 1 gram of water equal 1 cubic centimeter approximately

$P=\frac{W-D}{V}\times 100$ = per cent absorption in terms of the volume, which is the apparent porosity.

2. TABULATED RESULTS AND DIAGRAMS

In some cases considerable variation is shown in three apparently similar test pieces but as a whole the results are fairly concordant. It is regrettable that the limited equipment would not permit retesting the mortars which were impermeable under the

1.405 kilograms per square centimeter (20 pounds per square inch) pressure under a greater pressure in order to show their relative values. A summary of the results are reported in tables and some comparisons are shown diagrammatically.

Tables 1 and 2 (Figs. 10 to 13).—In nearly every case the mortars 26 weeks old are less permeable than those 8 weeks old, which in turn were less permeable than those 4 weeks old.

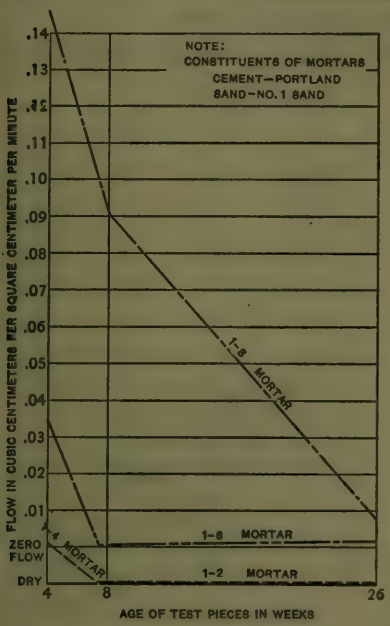

Fig. 10.—*Permeability of Mortars.*

Quaking consistency—Test pieces 1 inch thick. Hydrostatic pressure 1.4 kilograms per square centimeter.

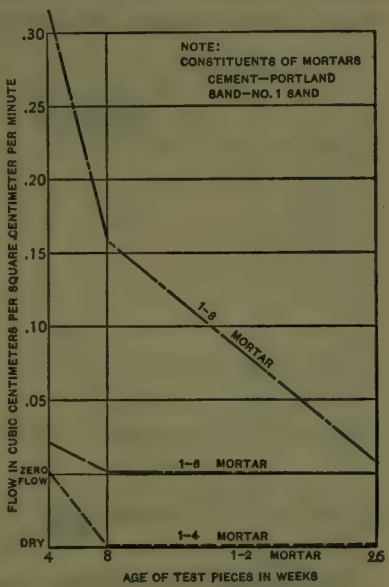

Fig. 11.—*Permeability of Mortars.*

Quaking consistency—Test pieces 2 inches thick. Hydrostatic pressure 1.4 kilograms per square centiemeter.

The richer the mixture in cement the less permeable was the mortar.

The quaking consistency was less permeable than the damp consistency.

The quantity of water passing decreases with the continuation of the flow.

The permeability was approximately the same for similar mortars whether in a 1, 2, or 3 inch thickness of test piece.

Table 3.—Comparing with Tables 2 and 3, the coarse sand mortar was more permeable than the finer grain sand mortar.

The permeability of the mortar decreased with its age.

The quantity of water passing decreased with the continuation of flow.

Table 4 (Figs. 14 and 15).—The concretes richest in cement were least permeable.

The permeability of the concrete decreased with its age.

The concrete showed very slight or no decrease in the quantity of water passing, with the continuation of the flow.

The 3-inch thickness of test piece is slightly less permeable than

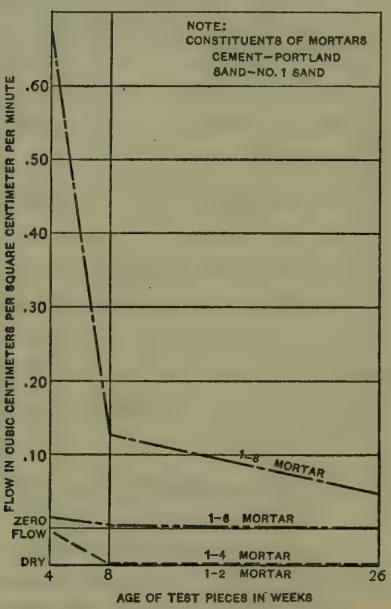

Fig. 12.—*Permeability of Mortars.*

Quaking consistency—Test pieces 3 inches thick. Hydrostatic pressure 1.4 kilograms per square centimeter.

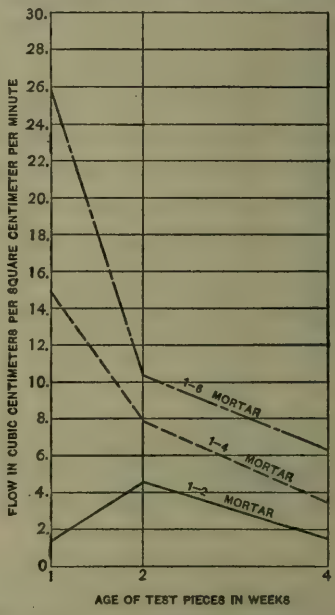

Fig. 13.—*Permeability of Mortars.*

Damp consistency—Test pieces 2 inches thick. Hydrostatic pressure 1.4 kilograms per square centimeter.

the 2-inch, which might be expected considering the size of the aggregate.

Table 5.—The retested test pieces showed practically the same relative decrease in permeability as corresponding mortars of the same age which had not been previously tested.

Table 6 (Figs. 16 and 17).—Concretes made with sand No. 4 were slightly more permeable than those made with sand No. 5, which contained the greatest percentage of fine material.

The same proportion, 1 to ½ to 5 parts, respectively, of cement, sand, and stone was the most impermeable with both sands.

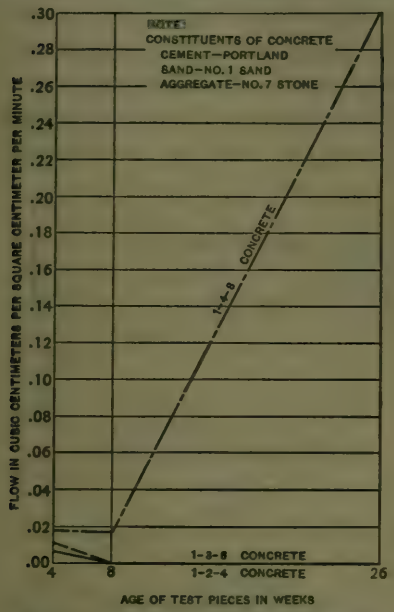

Fig. 14.—*Permeability of Lime Stone Concrete.*

Quaking consistency—Test pieces 2 inches thick. Hydrostatic pressure 1.4 kilograms per square centimeter.

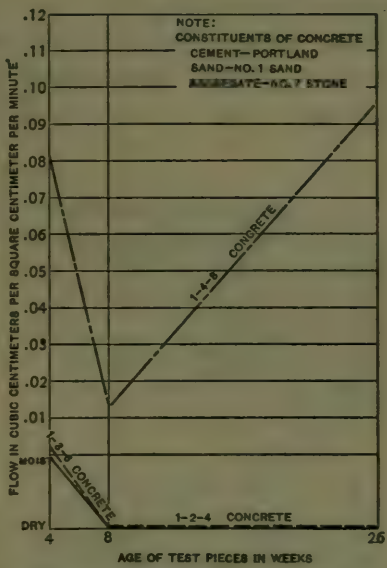

Fig. 15.—*Permeability of Lime Stone Concrete.*

Quaking consistency—Test pieces 3 inches thick. Hydrostatic pressure 1.4 kilograms per square centimeter.

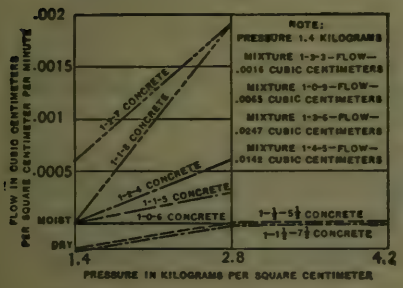

Fig. 16.—*Permeability of Concrete.*

Quaking consistency—Test pieces 6 inches thick. Age 13 weeks—Aggregate No. 4 sand, and No. 6 stone.

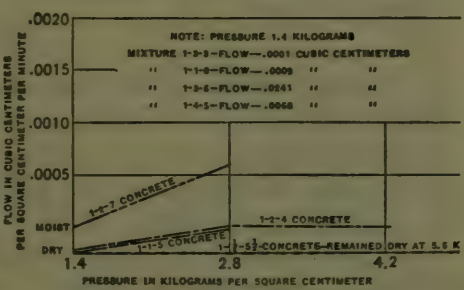

Fig. 17.—*Permeability of Concrete.*

Quaking consistency—Test pieces 6 inches thic Age 13 weeks—Aggregate No. 5 sand, and No. 6 stone.

These tests showed that the permeability of concrete was not dependent entirely on the quantity of cement used in proportion to the total aggregate but depended also upon the ratio of coarse

aggregate to fine aggregate. It will be observed in the case of sand No. 4 that the 1 to 1½ to 7½ proportion was decidedly more impermeable than the 1 to 2 to 4 proportion, although the former contains considerably less cement in proportion to aggregate.

Table 7 (Fig. 18).—The richer the mixture the more impervious the mortar. The permeability of the mortars decreases rapidly with age. The 1–5 and the 1–6 mortars were as impermeable

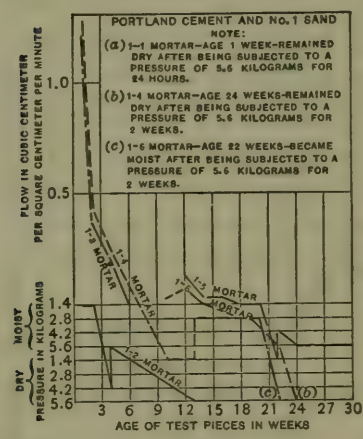
PORTLAND CEMENT AND No. 1 SAND
NOTE:
(a) 1–1 MORTAR—AGE 1 WEEK—REMAINED DRY AFTER BEING SUBJECTED TO A PRESSURE OF 5.6 KILOGRAMS FOR 24 HOURS.
(b) 1–4 MORTAR—AGE 24 WEEKS—REMAINED DRY AFTER BEING SUBJECTED TO A PRESSURE OF 5.6 KILOGRAMS FOR 2 WEEKS.
(c) 1–6 MORTAR—AGE 22 WEEKS—BECAME MOIST AFTER BEING SUBJECTED TO A PRESSURE OF 5.6 KILOGRAMS FOR 2 WEEKS.
FLOW IN CUBIC CENTIMETER PER SQUARE CENTIMETER PER MINUTE
1.0
0.5
1–8 MORTAR
1–6 MORTAR
1–5 MORTAR
1–4 MORTAR
1–3 MORTAR
1–2 MORTAR
MOIST
DRY
PRESSURE IN KILOGRAMS
1.4
2.8
4.2
5.6
1.4
2.8
4.2
5.6
(c)
(b)
3 6 9 12 15 18 21 24 27 30
AGE OF TEST PIECES IN WEEKS

Fig. 18.—*Permeability of Mortars.*

Quaking consistency—Test pieces 2 inches thick. Hydrostatic pressure 1.4 kilograms per square centimeter.

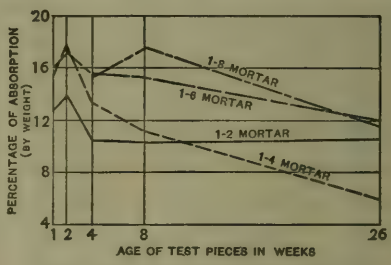

Fig. 19.—*Absorption of Mortars.*

Damp consistency—Portland cement and No. 1 sand.

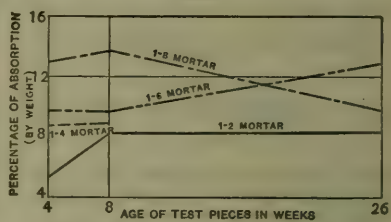

Fig. 20.—*Absorption of Mortars.*

Quaking consistency—Portland cement and No. 1 sand..

at 22 weeks as the 1–2 mortar was at 2 weeks. The value of troweling the surface is shown by these results.

Table 8 (Figs. 19 and 20).—The richer the mixture in cement the less the absorption of the quaking-consistency mortars, but the richness had less effect in the damp-consistency mortars.

The absorption was less in the quaking-consistency mortars than in the damp-consistency mortars.

The absorption increased with age from the first to the second week in the damp-consistency mortars but decreased from the second to the twenty-sixth week.

Table 9 (Figs. 21 and 22).—The absorption decreased but slightly with the richness of the mixture except in the 1–2 mixture of damp consistency, which showed a decided reduction.

The absorption was less in the quaking-consistency mortars than in the damp-consistency mortars.

The absorption decreased with age in the 1–4, 1–6, and 1–8 damp-consistency mortars and 1–2, 1–4,. and 1–6 quaking-consistency mortars, but slightly increased with age in the 1–2 damp-consistency and 1–8 quaking-consistency mortars.

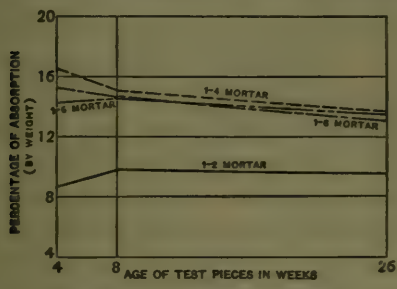

Fig. 21.—*Absorption of Mortars.*

Damp consistency—Portland cement and No. 2 sand.

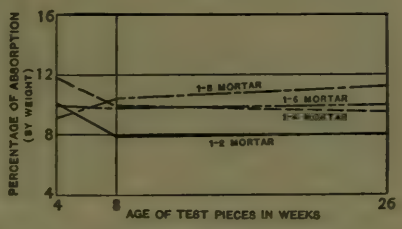

Fig. 22.—*Absorption of Mortars.*

Quaking consistency—Portland cement and No. 2 sand.

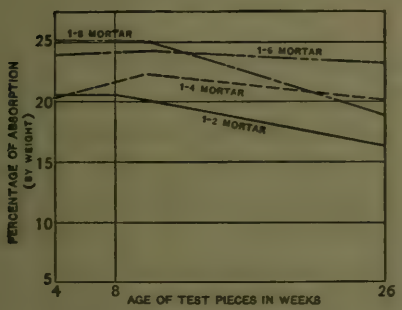

Fig. 23.—*Absorption of Mortars.*

Damp consistency—Portland cement and No. 3 sand.

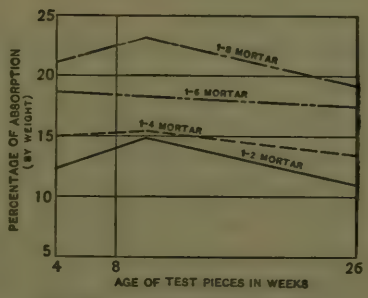

Fig. 24.—*Absorption of Mortars.*

Quaking consistency—Portland cement and No. 3 sand.

Comparing these tables with Table 8, it will be observed that the age of a mortar does not affect its absorption so much in the coarse sand mortar as in the finer sand mortar.

The coarse sand mortars were slightly less absorptive than the finer sand mortar.

Table 10 (Figs. 23 and 24).—The absorption decreased but slightly with the richness of the mixture.

The quaking-consistency mortars were less absorptive than the damp-consistency mortars.

The absorption decreased with the age of the mortar but not so markedly with the leaner mixtures.

Comparing with Table 8, it will be observed that the slag sand mortars were very absorptive, which was probably due to the porous nature and uniform size of the sand grains.

PART II

TESTS OF DAMP-PROOFING AND WATERPROOFING COMPOUNDS AND MATERIALS

An endeavor was made to conduct these tests in such a manner as to make the results of practical value as a determination of the comparative values of the various so-called "waterproofing" and "damp-proofing" mediums.

Forty different compounds were purchased in the open market and several void-filling materials were obtained for testing. A complete record of each compound is reported as to its character, chemical analysis, method of application, the result of physical tests, and noted peculiar characteristics.

Considerable difficulty was experienced in devising a method of testing which would be applicable to all compounds, making the results directly comparable and at the same time complying with the directions for using the compound as recommended by the manufacturer.

The compounds are of two general classes, the waterproofing compounds for preventing the flow of water through masonry where subjected to a hydrostatic head, as in reservoirs, cisterns, tunnels, cellars, and the like; and damp-proofing compounds for overcoming dampness resulting from the capillary attraction and absorptive qualities of masonry, preventing dampness in habitations, and the disfigurement of exterior and interior surfaces of brick, stone, and concrete walls and interior plastering and decorations due to staining and efflorescence. Many of the waterproofing compounds are also recommended for use as damp-proofing mediums.

Two series of tests were made in this investigation, one of the waterproofing or water-resisting qualities of the compounds recommended for such use, and another of the damp-proofing qualities of other compounds so recommended to be used. Some of the coating compounds were recommended for use as waterproofing mediums, but after testing two or three and finding that they failed utterly it was decided to first test all coating compounds as

damp-proofing mediums. All the waterproofing compounds tested and reported were such as were to be incorporated in a mortar or concrete and are known as "integral" compounds. No tests were made on felt papers or similar materials coated with bitumen or similar materials.

The Portland cement used in these tests was the same as described in Part I, where its physical and chemical qualities are given.

Only one kind of sand was used throughout these tests, the Meramec River sand, a description of which, with its physical properties, is given in Part I.

VIII. WATERPROOFING AND DAMP-PROOFING MATERIALS

The compounds tested were purchased from the makers or their agents under the following trade names

Anhydrol
Antihydrine
Anti-Hydro
Aquabar
Aquarex
Astralite
Blanchite
Carbonkote
Cement Filler
Cement Floor Paint
Dehydratine No. 2
Dehydratine No. 4
Fibrous
Hydratite
Hydrolithic Coating
Ideal Filler
Impervo
Ironite
Irono
Lewis
Limoid
Liquid Konkerit
Maumee
Medusa
Minwax
Morganite
Novoid
Parine
R. I. W. No. 232
R. O. U. Compound
R. O. U. Liquid
Standard
Star Stettin Waterproof Cement
Te-Pe-Co.
Toxement
Universal Damproof
Waxin
Waxol
Weatherproof Granite
Wunner's Bitumen Emulsion

The above list includes practically all types of compounds which have been recommended and used for waterproofing and damp proofing with the exception of plastic coatings reinforced with fabric.

1. CLASSIFICATION OF COMPOUNDS

The tests of compounds are reported in this paper by number only, no specific reference being made to their commercial name nor to the manufacturer. They are classified according to composition in the following table of compounds:

- Coating
  - Linseed oil paints and varnishes (compounds Nos. 1, 2, 3, 4, 5, 6).
  - Bitumens
    - Asphaltums (compounds Nos. 7, 8, 9, 10).
    - Mixtures of various bitumens (compounds Nos. 11, 12, 13, 14).
    - Mixtures of bitumen with wood tar and linseed oil.
  - Liquid hydrocarbons (compounds Nos. 15, 16, 17, 18, 19).
  - Soaps (compounds Nos. 20, 21, 22).
  - Cements (compound No. 23).
  - Miscellaneous (compounds Nos. 24, 25, 26).
- Integral
  - Solids
    - Inert fillers (compounds Nos. 27, 41, 42, 43 44, 45).
    - Active fillers (compound No. 28).
    - Antipathetic or water repelling substances (compounds Nos. 29, 30, 31, 32, 33, 34, 35, 36).
    - Cements (compound No. 37).
  - Liquid, active (compounds Nos. 38, 39, 40).

This classification has been adopted, first, because all the compounds investigated have been designed for use in either of these two ways; that is, to be applied either to an outer or inner wall as a wash, plaster, or impervious membrane "coating," or to be mixed with the dry cement or mixing water to form an integral part of the resulting mortar or concrete. It may be said, however, that frequently the manufacturer of the second class of compounds recommends his product to be used also as a wash, when

mixed with cement, or cement and water, to the consistency of a cream. But this is a secondary use, and they prefer to have their material incorporated into the mass. Second, this extended classification shows what the compounds have been found to contain and what they really are, notwithstanding any claim of the manufacturers. In some cases there has been some doubt as to which class a compound belonged. For example, the majority of the water-repelling compounds contain such a very large percentage of totally inert material that they might well be placed among the "inert fillers," but they do contain a slight percentage of insoluble soaps which repel water, hence they have been classed as such.

2. CHEMICAL REVIEW

As no organic substances can be considered as truly permanent, the durability of all these compounds, except the inert fillers, can be questioned.

a. COATING COMPOUNDS

(a) **Linseed Oil Paints, Varnishes, etc.**—The compounds in this class differ in nowise from the ordinary enamel paints which are usually characterized by hardness and brittleness, due to the comparatively large amount of hard resins and the small amount of linseed oil. This causes such coatings to be very inelastic, but at the same time would apparently increase the life of the coating, since the hard resins are more inert than the linseed oil. Linseed oil is constantly undergoing changes due to oxidation, and in the presence of alkali its life is still further decreased owing to the saponification which takes place in the presence of the latter. It will be noted from the remarks under the damp-proofing tests that nearly all these coatings softened under the influence of water, thus showing that saponification was taking place.

(b) **Bituminous Coatings.**—This class includes asphalt, petroleum residuum, and coal-tar pitches. They are usually characterized by great inelasticity, and are, therefore, recommended to be used with alternating layers of felt, and being solid at ordinary temperatures are applied while hot. As they are also soluble in benzine and coal-tar naphtha they are frequently put on the market in this latter form. The materials included in this class

have, somewhat unfortunately, with one exception, been of this form. Owing to their wide distribution, their cheapness, the ever-increasing quantities which are appearing on the market, and their supposed inertness, it has been deemed advisable to make a further study of this single class. This study will include a more detailed chemical investigation and comparison of the various bitumens when subjected to various conditions, as water on one side of the bitumen and air on the other side, water on both sides, action of waters containing various salts, etc.

(c) **Liquid Hydrocarbons.**—In this class there are two kinds of compounds which act largely to fill the pores and at the same time repel water. Both are of such a nature that they do not penetrate the mass very far and are only very superficial. Like all coatings, they are rendered worthless by any minute crack in the concrete. The nonvolatile part of one of them is paraffin, which is inert, and in the other it is largely a petroleum oil, which remains unacted upon and under a slight head of water would be forced out.

(d) **Soaps.**—The use of a solution of soaps can not bring enduring results. It is quite likely that very much more of the soap is dissolved and washed off the surface than ever reacts to form insoluble compounds of the nature of lime soap. Unless such reaction does take place, which is doubtful, this class is entirely worthless.

(e) **Cements.**—There are a number of cements on the market to which have been added a very small quantity of water-repellent substances. This makes them similar to the "water-repelling" compounds discussed under that classification.

(f) **Miscellaneous Coatings.**—This class includes a number of compounds of very diverse nature. For this reason their value is discussed in detail in connection with the statement of the analyses.

b. INTEGRAL COMPOUNDS

(a) **Solid Inert Fillers.**—This class includes a number of finely ground, naturally occurring materials such as clay, sand, and a prepared filler, or hydrated dolomitic lime. The use of cement in large quantities—"rich mixes"—also places that substance to a certain extent in this class. A further discussion of this class is

hardly necessary, since it would finally resolve itself into the question of the density of the mixture. The fillers used, however, should not only be inert toward the action of the cement but also to atmospheric conditions and possible percolating waters. Hydrated lime can hardly be considered inert in this respect, though hydrated dolomitic lime would be much more so.

(b) **Active Fillers.**—This class includes several compounds which are supposed to react with certain of the constituents of the cement to form other compounds which at the same time will be inert and fill the voids. One of these is partly a resinate of potash which, in the presence of the free lime of the concrete, would react to form the more insoluble resinate of lime; the rest of the compound is, however, inert. Another contains a large quantity of saponifiable oil, which again forms an insoluble lime soap with the concrete. These lime soaps are not only almost insoluble in water but they are also not wet by it, consequently they form the basis of the succeeding class, the "water-repelling" compounds. As, however, in themselves these materials are not waterproofing but become so only as a result of a series of reactions, it would be better to use the result of these reactions directly and not depend upon something that may not always take place either wholly or in part. Consequently, it is better to use the water-repelling compounds themselves if this kind of material is desired.

(c) **Water-repelling Compounds.**—These are stearates of lime or soda and potash. The former, as stated above, is almost insoluble in water and is also not wet by it. Upon this latter fact, together with a large amount of hydrated lime (or lime and magnesia) present in them, acting as an inert void filler, depends the value of the compound. The stearates of soda and potash are ordinary soap, readily wet and soluble in water. With these there is a reaction when they are treated with water in the presence of the cement; the soda or potash soap is dissolved and precipitates the more insoluble lime soaps, the result being the same compound as the rest of this class contains. The claim made by the manufacturers that these compounds are water repellent is inconsistent, in that they must be thoroughly surrounded by water when mixed with the aggregate if the normal strength of

the concrete is to be developed. When so mixed in the concrete their water-repellent action would be lost. If it repels the water from the concrete it must necessarily repel it from the cement and prevent the latter from attaining its usual strength.

(d) **Waterproofing Cements.**—Several manufacturers have added water-repelling materials directly to cement and offered it to the public as waterproofed cements. This repelling material is similar to that used in the water-repelling compounds, consequently the remarks made under that class apply here.

3. CHEMICAL ANALYSES

The following are the analyses of the compounds investigated, grouped in the classes mentioned above:

a. COATING COMPOUNDS

(a) **Linseed-oil Paints, Varnishes, etc.**—One would expect to find in the paints used for waterproofing or damp-proofing cements a relatively large amount of resins; in the case of an enamel paint it is reasonable to expect that a short oil varnish was used in its manufacture. By putting more resins in the material, the manufacturer puts more of a stable compound in it, as opposed to the more unstable material—linseed oil. This latter will not only readily react with the alkaline water coming through the cement, but also is continually subjected to oxidation. In both of these respects the resins are much more stable.

As can be seen from the following analyses this is true in several cases. Of course it is impossible to replace all or nearly all of the oil by resin, since by doing so would give a very brittle, inelastic coating, which is so little desired.

The figures given for the insoluble resins may be taken as a relative measure of the total resins present. It is to be regretted that there is no method which will give the exact amount present. The methods used by Holly and Ladd (Analysis of Mixed Paints, Color Pigments, and Varnishes, by Holly and Ladd), by the Department of Agriculture (Bull. 109, Bureau of Chemistry), and McIlheny (Proceedings American Society for Testing Materials, 1908), give only more or less close approximations of the amount present. None pretend to give the amount actually present.

By "insoluble resins" in the following analyses is meant the resins insoluble in 87° (Baumé) gasoline.

Attempts have been made to make special cement paints. One of them put on the market was purported to be a synthetic tricalcium silicate. This same pigment also contained 50 per cent lithophone. Others have added Portland cement to varnishes and placed them on the market, but these decompose so quickly, the oil reacting with the cement, that they were withdrawn. It would seem from the analysis of the paints used in the present series of permeability tests that no special pigment has been used.

The volatile material or thinner used in these compounds is also that common to ordinary paints and varnishes.

Compound No. 1

	Per cent
Pigment	18.84
Linseed oil, driers, and soluble resins	14.81
Insoluble resins	24.03
Volatile (coal-tar naphtha, turpentine, and benzine)	42.32
	100.00

(The driers are lead, manganese, and lime resinates.)

Pigment:

Silica	4.64
Alumina	3.24
Iron oxide	1.74
Lime	0.39
Barytes	57.66
Zinc sulphide	31.98
	99.65

This was an enamel paint characterized by a rather large amount of insoluble resins. The lime resinate is common to both the best and cheapest varnishes. The pigment is largely the material sold under various trade names as lithophone, Beckton white, phonolith, etc. It has thus far not been possible to produce a stable pigment of this character. Although a beautiful white with considerable covering power, it invariably darkens when exposed to sunlight, later bleaching out slowly. In the present case the pigment is of a cement color, tinted by the other materials shown in the analysis. Whether the lithopone has reached a stable condition is unknown.

Compound No. 2

	Per cent
Pigment	19. 52
Linseed oil, driers, and soluble resins	66. 28
Insoluble resins	3. 18
Volatile (benzine 83 per cent, turpentine 17 per cent)	11. 02
	100. 00

(The driers are lead and manganese resinates.)

Pigment:	
Lead oxide (litharge)	10. 44
Lampblack	87. 43
Alumina silicate	1. 91
	99. 78

This is a good example of a black paint such as can be bought on the market for almost any purpose. As a paint, nothing can be said against it, excepting the use of lead oxide, which is constantly combining with the oil to form a difficultly soluble soap which settles to the bottom of the container and makes almost impossible the proper incorporation of the pigment with the oil.

Compound No. 3

	Per cent
Linseed oil, driers, and soluble resins	17. 42
Insoluble resins	15. 35
Volatile (benzine 90 per cent, turpentine 20 per cent)	67. 23
	100. 00

(The driers are lead, manganese, and lime resinates.)

This is a very heavy viscous "Japan." The use of lime resinate is not generally to be favored. The "linseed oil" is strongly suspected of being "China wood oil," but it is not positively identified in the presences of the large amount of resinates.

Compound No. 4

	Per cent
Pigment	75. 06
Linseed oil, driers, and soluble resins	7. 43
Insoluble resins	3. 46
Volatile (benzine 80 per cent, turpentine 20 per cent)	14. 05
	100. 00

(The driers are lead and manganese resinates.)

Pigment:	
China clay—	
Silica	19. 37
Alumina	7. 74
Whiting—	
Calcium carbonate ($CaCO_3$)	31. 13
Magnesium carbonate ($MgCO_3$)	0. 59
Zinc white	41. 19
	100. 02

This was a paste which is to be mixed with benzine or turpentine before applying. When applied it is supposed by the makers to first set by evaporation and then to oxidize but not to crack, peel, or become brittle. There is nothing to distinguish it from any other white "pastes" on the market to be used for general purposes.

Compound No. 5

	Per cent
Pigment	58.85
Insoluble resins	4.72
Linseed oil, driers, and soluble resins	24.60
Volatile (benzine)	11.83
	100.00

(The driers are lead and manganese resinates.)

Pigment:	Per cent
White lead	24.55
Barytes	8.48
Silica	23.34
Alumina	0.38
Iron oxide	0.21
Gypsum	15.76
Lime	1.08
Magnesia	0.34
Zinc oxide	21.60
Zinc sulphide	1.68
Lampblack	2.32
	99.74

This is a paint characterized more by a large variety of materials in the pigment than anything else. The reason for using such a number is unknown; the shade—that of cement—does not require them. One can expect no better results from this than from an ordinary paint.

Compound No. 6

Distillates:	Per cent
Up to 105° (benzine and light oils)	19.40
105 to 145° (benzine and light oils)	41.00
145 to 305° (light yellow oils)	2.40
Volatile at 105°	56.06
Unsaponifiable (black viscous petroleum oil)	23.65
Saponifiable	20.29
	100.00

The saponifiable is largely linseed oil; some resins are also present, combined with lime and manganese.

This compound is a mixture of benzine, linseed oil, lime and manganese resinates, and a petroleum oil. In a very thin layer it will dry in about four weeks. Applied on concrete the linseed oil would be partly converted into linoleate of lime, which is insoluble; the benzine would evaporate and the petroleum oil remain inert, filling the surface pores. Under any considerable head of water it would be forced out.

(b) **Bitumens.**—The four following compounds are classed as asphaltums, though they may be residuums of petroleum, having an asphaltum base. Letters have been received from three of the manufacturers of the four compounds of this class, in which they state that their material will not stand the weather; and two state explicitly that it must be used between the wall and plaster and not be exposed, hence no discussion of their weathering properties is necessary.

In analyzing these compounds the percentage of volatile at 105°, the percentage of saponifiable calculated to be a linoleate, and the percentage of unsaponifiable were obtained. The material was also distilled up to 315°, changing the receiver whenever the distillate was noticed to change. When turpentine was suspected to be present a distillate was caught between 150 to 170°, and in this the amount of turpentine was determined.

Compound No. 7

Distillates:	Per cent
Up to 105°	27.00
105 to 150°	15.00
(Benzine and light oils.)	
150 to 315° (changed to yellow oil at 150° and continued so until end)	5.00
Volatile at 105° (benzine and light oils)	40.10
Nonvolatile	59.90

	Per cent
Bitumen and oils	97.69
Free carbon	.39
Ferruginous clay	2.15

The bitumen is a mixture of asphaltum and petroleum residuum.

Compound No. 8

	Per cent
Volatile at 105°	58.70
Saponifiable (resinates, resins, and linseed oil)	21.30
Unsaponifiable (asphaltum)	20.00
	100.00

(Lead and manganese driers are present.)

Distillates:	Per cent
Up to 105° (naphtha)	1.70
105 to 150° (benzine)	24.80
150 to 170° (benzine 85 per cent, turpentine 15 per cent)	28.40
170 to 315° (light yellow oil, containing acrolein)	11.00

This compound contains considerable linseed oil, which tends to make it more elastic. It also tends to make it reactive (less inert) to atmospheric conditions.

Compound No. 9

Distillates (start at 200°):	Per cent
200 to 315° (yellow oil, cloudy from presence of a wax)	9.00
Acetone extracts (dark-brown soft, waxy material)	19.30
(Chloroform almost completely extracts the residuum of the acetone.)	
Nonextractable	.15
Ash (SiO_2:Al_2O_3)	.21

This compound is a solid which becomes plastic at 30° and melts at 110°.

The material would seem to be a natural-occurring bituminous wax, especially so on account of the very small amount of free carbon and the large amount of wax.

Compound No. 10

	Per cent
Volatile at 105°	32.88
Nonvolatile	67.12
	Per cent
Asphaltum and heavy oil	97
Ash ($CaCO_3$)	3
Trace nonsoluble organic matter.	
Distillates:	
Up to 105°	6.50
105 to 205°	24.50
(Benzine and light oils.)	
205 to 315° (heavy yellow oil)	10.00

(c) **Mixtures of Various Bitumens with Linseed Oil, etc.**—There are four compounds in this class, which covers a large variety of mixtures. The makers seemed to have had one purpose in mind in making these, however—to make the materials more elastic by the addition of a drying oil, as linseed oil. It is a question if they have not sacrificed durability by this addition, since it is very likely that the bitumen alone on the concrete would last longer and be more inactive than with the readily oxidizing and very active and drying oils.

Compound No. 11

	Per cent
Extractable with 87° gasoline (73.7 per cent saponifiable (linseed oil and resinates). Remainder is coal-tar oils)	23.70
Extractable with carbon bisulphide. (Coal-tar pitch.)	11.82
Nonextractable	29.72
Carbon and hydrocarbons	23.80
Silica	14.06
Iron oxide	62.32
	100.18
Volatile (coal-tar naphtha)	34.76
	100.00
Distillates:	
Up to 105°	44.00
105 to 165° (Coal-tar naphtha and light oils.)	16.00
165 to 315° (a yellow heavy oil containing acrolein)	5.00

(Lead and manganese driers are present.)

Compound No. 12

	Per cent
Extracted with 87° gasoline (69.5 per cent saponifiable, calculated as linoleate (linseed oil and resinates); 30.5 per cent hydrocarbons)	59.52
Extracted with chloroform (a very brilliant, brittle coal-tar pitch)	4.96
Nonextractable (a dull-black powder resembling ground coal)	24.28
Carbonaceous	31.76
Silica	23.00
Alumina	19.36
Iron oxide	10.45
Lime	9.30
Magnesia	5.76
	99.63
Volatile (90 per cent benzene and 10 per cent turpentine)	11.24
	100.00

(Lead and manganese driers are present.)

Compound No. 13

Distillates:	Per cent
Up to 105°	5.20
105 to 150°	29.20
150 to 170° (Benzine: Turpentine was suspected but proved to be a substitute (benzine and essential oil).)	7.00
170 to 315° (heavy yellow oil)	5.00
Volatile at 105° (benzine)	31.50

(Residue is a mixture of wood-tar pitch and possibly asphaltum.)

Compound No. 14

Distillates:	Per cent
Up to 105° (wood alcohol, coal-tar naphtha, and benzine)	7.00
105 to 165° (coal-tar naphtha and benzine	34.00
165 to 315° (light yellow oil)	11.00
Volatile at 105°	39.90
	Per cent
Wood alcohol	5
Benzine (approximately)	65
Coal-tar naphtha (approximately)	30
Nonvolatile (soluble in acetone; contains saponifiable equivalent to 36 per cent linoleate; resins, driers, and hydrocarbons present)	31.20
Petroleum residuum	28.90
	100.00

(Lead and manganese driers are present.)

(d) **Liquid Hydrocarbons.**—There are two kinds of compounds in this class—the first is a solution of paraffin in benzine and benzol. This kind of a material has been used for a long period and has many advocates. It is readily applied to a dry wall; to a wet one it will not adhere, consequently it can not be used to stop the flow of water through a pervious wall.

The second compound is an emulsion of a petroleum oil, fat oil, with water secured by means of the use of a little ammonia. The petroleum oil would naturally render the wall water repellent and the fat oil might form a soap in the concrete which would fill the voids. The ammonia would soon volatilize.

Compound No. 15

Distillates:	Per cent
Up to 105°. (A little water, benzol, and benzine)	30.00
105 to 165° (5 per cent low-boiling turpentine (recovered from wood chips), light-burning oils)	24.50
165 to 315° (light yellow oils containing a little paraffin)	28.50
(Residue is a soft brown paraffin).	
Volatile at 105° (benzol and benzine)	80.75

Compound No. 16

	Per cent
Water	84.99
Ammonia	.23
Petroleum oil	9.78
Fat oil	5.00
	100.00

The petroleum oil is paraffin oil.

The fat oil was not positively identified; it was semidrying and had some of the characteristics of rape oil.

The ammonia is reported as anhydrous.

The above is a very stable emulsion of the oils and water; on long standing a little oil separates out but is very readily incorporated again by slight shaking. We doubt whether the oils would remain in the pores of the concrete under a very slight head. The fat oil is a very slow drying one in itself; mixed with the petroleum oil it is entirely nondrying, also very slowly saponifiable.

Compound No. 17

	Per cent
Distillates:	
110° (water, benzol, and benzine)	31.5
110 to 165° (water, light-burning oils, and 7 per cent turpentine)	30.3
165 to 260° (yellow paraffin oil and 22 per cent turpentine)	17.2
260 to 315° (yellow viscous oil)	5.5
(Residue is a soft brown paraffin.)	
Volatile at 100°	79.2

The material is benzol, benzine, wood turpentine, paraffin oils, and paraffin.

Compound No. 18

	Per cent
Volatile at 105°	66.5
Nonvolatile (paraffin; melting point, 46°.1)	33.5
Distillates:	
98 to 130° (naphtha and benzol)	50.0
130 to 190° (benzine)	15.3

The material is paraffin dissolved in petroleum and coal-tar naphtha.

Compound No. 19

	Per cent
Volatile at 105°	77.6
Nonvolatile (paraffin; melting point, 44°.4)	22.4
Distillates:	
158 to 193° (benzine, benzol, and 13 per cent wood turpentine)	50.0
193 to 249° (light yellow oil)	16.0
249 to 325° (light yellow oils)	6.0

The material is paraffin dissolved in pertoleum and coal-tar naphtha, wood turpentine, and light petroleum oil.

(e) **Soaps, Solid and in Solution.**—The use of soap solution in connection with alum is one of the oldest waterproofing methods. The use of soap alone is more recent and less frequently used. The value of the soap alone is also rather doubtful, since it is soluble in water

and may easily wash away if used as a coating before reacting with the concrete to form insoluble soaps. This latter is accomplished almost immediately in the soap-alum process on adding the alum wash.

The nature of the compounds in this class is apparent from their analyses.

Compound No. 20

	Per cent
Water	96.00
Soap	3.91
(The soap is potassium linoleate.)	

According to the manufacturer, the value of this compound is due to the hardening of solids contained in the emulsion. They can not be washed away or changed by oxidation. As this is simply a solution of soap and water, it is difficult to see how the makers' claims can be fulfilled. If there is no reaction between the lime of the cement and the potassium of the soap, the latter will inevitably go into solution when in contact with water.

Compound No. 21

	Per cent
Water	8.15
Soda (Na_2O)	8.71
Potash (K_2O)	.43
Free fat	10.45
Fat acids (a mixture of fat acids at 30° consists of a liquid acid with a large quantity of crystalline acid)	67.12
Rosin	2.90
Blue vitriol ($CuSO_4$)	2.65
	100.41

This soap has been made partly of a fish oil. The purpose of the copper sulphate is unknown unless as a germicide or fungicide.

Compound No. 22

Distillates:	Per cent
80 to 150° (benzine, sp. gr. 0.757)	10.2
150 to 200° (benzine, sp. gr. 0.782)	35.8
200 to 260° (light yellow oil, sp. gr. 0.821)	34.0
260 to 310° (yellow oils, sp. gr. 0.841)	10.0
Nonvolatile at 105° (yellow paraffin, 3.7 per cent; remainder alumina resinate)	3.2

The material is a mixture of paraffin, light yellow petroleum oil, benzine, and alumina resinate.

(f) Cements as Coatings.—The addition of a water-repelling material to a cement to be used either as a coating or directly in making mortars and concretes has often been suggested, and several of such products are now on the market. Two of these have been used in the present investigations—one, however, as a coating and the other directly as a cement.

The analysis of the former follows. It will be seen that the cement has been mixed with a large quantity of sand. See also the remarks under "Water-repelling compounds," following later

Compound No. 23

	Per cent	Per cent
Passes 100-mesh sieve		27.73
Silica	22.40	
Alumina	7.98	
Iron oxide	3.63	
Lime	59.34	
Magnesia	1.85	
Sulphuric anhydride	1.15	
Carbon dioxide	2.16	
Organic	.32	
Water	.93	
	99.76	
Retained on 100-mesh sieve		72.27
		100.00

(The organic is fat acids with a melting point of 52° and the combined weight of 268; they are present as a lime soap.)

	Per cent
Silica	54.09
Alumina	4.47
Iron oxide	1.36
Lime	13.47
Magnesia	7.72
Ignition loss (carbon dioxide=18.13 per cent)	18.27
	99.38

(This is a sand (all passing one-eighth sieve) composed of quartzite and dolomite. There is a trace of fat acids also present.)

(g) Miscellaneous Coatings.—Four compounds have been placed in this class. They are distinct from each other and the other compounds examined. Their analyses follow, together with such remarks as will make their composition and possible value clear.

Compound No. 24

	Per cent
Silica	27.27
Alumina	.79
Iron oxide	.52
Lime	23.91
Magnesia	14.02
Sodium oxide	.26
Potassium oxide	Trace
Sulphuric anhydride	1.01
Carbon dioxide	15.50
Casein	3.19
Glue	8.48
Water	4.82
	99.77

This is a mixture of asbestos, whiting, casein, glue, and possibly a little free or hydrated lime to hold the casein in solution. This is the only compound examined which contained casein, which fact is rather peculiar in view of its well-known use in "cold-water paints," where it has been highly successful. The glue has no value for waterproofing. Some preservative—as boracic acid—should have been added to this material, as in damp places it rapidly decomposes, giving rise to very offensive odors.

Compound No. 25

	Per cent
Carbon	3.92
Silica	4.40
Manganese	.57
Phosphorus	1.00
Sulphur	.12
Lime	1.02
Magnesia	.25
Iron	85.04
Sal ammoniac	3.49
	99.81

According to the manufacturer this compound is a filler, but applied on the surface in a water-paste form. Hence, it can only be a surface filler and does not penetrate. There may be a reaction between the concrete and the material; but the one reaction upon which the value of the compound depends is the corrosion of the iron by the sal ammoniac in the presence of water. If the resulting corroded iron will adhere to the concrete, the material should have considerable value as a waterproofing material.

Compound No. 26

	Per cent
Volatile at 105° (water with less than 0.10 per cent phenol)	93.90
Fat acids (mostly stearic)	.80
Glue	2.10
White lead	2.11
Lead oxide (litharge)	.94
Sodium oxide [2]	.03
Potassium oxide [2]	.05
	99.93

Another sample of this material was received at the laboratories and analyzed as follows:

	Per cent
Volatile at 105° (water, with a very little phenol)	92.58
Fat acids (largely stearic)	.85
White lead	3.52
Glue	2.85
Sodium oxide [2]	.04
Potassium oxide [2]	.06
	99.90

It will be seen that these materials differ in that the one contains litharge and the other does not. While the actual amount of the lead oxide may be small, especially in terms of percentage of material, yet in percentage of solids it is quite large. Its absence is also readily noticed by the color, the first material having a decided yellow or orange tinge, while the second is white. Later a third sample was received and this again contained litharge, judging from the color, in even larger amounts than the first sample. However, the material is intended to be an emulsion of soap, glue, white lead, water, and sometimes litharge. It may happen that during the evaporation of the water part of the lead oxide, especially when the litharge is present, combines with the glue to form a compound which, after evaporation, dissolves with difficulty. This is especially true when evaporated at 105° C.; the residue is then quite gummy and elastic and almost insoluble in water either hot or cold. When evaporated at ordinary temperatures the residue crumbles easily and when heated with water to about 70°C. it will form an emulsion like the original material.

[2] Combined with the fat acids, as soap.

b. INTEGRAL COMPOUNDS

All of the remaining compounds investigated are to be added directly to the cement before making it into mortar or concrete, or to the water used.

INERT FILLERS

Clays, Sand, Feldspar, Hydrated Lime

	No. 41, N. Y. clay	No. 42, fire clay	No. 43, Mo. clay	No. 44, feldspar	No. 45, sand	No. 27, hydrated lime
Silica	58.30	52.86	72.91	64.02	89.50	1.34
Alumina	16.85	32.36	15.01	19.38	2.36	.45
Ferric oxide	6.41	1.44	2.79	.70	2.58	.13
Manganese oxide	.06	.02	.03	Trace.	.12	.....
Lime	4.22	.39	.59	.87	1.37	46.90
Magnesia	2.92	.22	.85	.33	.57	32.19
Sulphuric anhydride	.12	.10	.12	.10	.21	[3] 4.02
Sodium oxide	.77	.21	.80	2.52	.26	.....
Potassium oxide	2.71	.43	2.12	11.76	.70	[4] 15.05
Water (105°)	.60	1.69	1.12	.06	.20	.....
Ignition loss	7.00	10.49	3.81	.54	2.35	.....
	99.96	100.21	100.15	100.28	100.22	100.08
Rational analysis						
Free silica	25.56	13.86	43.60	.....	.....	.....
Clay material	44.29	66.82	29.89	.....	.....	.....
Felspathic	22.55	7.14	21.58	.....	.....	.....
Ignition loss	7.60	12.18	4.93	.....	.....	.....

[3] Carbon dioxide.

[4] Total water.

(a) **Inert Fillers.**—The first class of this division of compounds comprises all the inert fillers; that is, those materials which act as void fillers or increase the density of the concrete and are without any action on the cement and do not themselves change. We have included in this class hydrated dolomitic lime, clays, finely ground sand, and finely ground feldspar. Some of these compounds may be partly changed in time when in the concrete. The hydrated lime may be partly carbonated, especially on the surface; the feldspar may decompose by the leaching out of the alkalies;

the sand will change but very little, being a high-grade quartz sand; the clays will be very inert, although some theories have been brought forward which assume a very important rôle for clay when mixed into concrete.

According to these theories, colloids (the plasticity of clays is a direct function of the amount of colloids present) are an excellent means of keeping slightly soluble salts in solution, in that they unite the salt ions and form aggregates which do not necessarily precipitate. By this means the precipitation of the slightly soluble salts is retarded or suppressed; in other words, the colloids of the clay protect the calcium compounds from quick hydration, and consequently prevent increase in volume due to chemical action.

The clays, sand, and feldspar were ground to pass a 200-mesh sieve before adding to the cement mortar. The analyses of these compounds follow.

(b) **Active Fillers.**—There is but one compound in this class. It is a white powder with a strong aromatic odor of kauri resin. This being in combination with potassium will possibly partly dissolve in the mixing water and in turn be decomposed by the lime present to the corresponding lime resinate, which is comparatively insoluble. The greater part of the compound is entirely inert, being china clay and hydrated lime.

Compound No. 28

	Per cent
Silica	46.66
Alumina	16.71
Iron oxide	.93
Lime	11.97
Magnesia	.72
Sulphuric anhydride	2.73
Soda	.34
Potassium oxide	1.44
Ignition loss	18.64
	100.14

(Extracted by alcohol=14.69 per cent=a resinate of potash.)

(c) **Water-Repelling Compounds.**—In this class of compounds we have stearic acid combined either with soda and potash or lime. The amount of these necessary to combine with the acid is not very great, in no case exceeding 7.5 per cent. Consequently it can be seen that the greater part of the material is hydrated

lime and magnesia lime. These act simply as void fillers. As a whole, they are inert toward the cement and water, according to the admissions of the manufacturers. However, those in which the stearic acid is combined with the soda and potash must react with the lime of the compound to form the more insoluble lime soap, or else they are valueless, owing to the ready solubility of the former soap in water.

The substance referred to as stearic acid is of course not a chemically pure stearic acid, or even in some cases a commercially pure article, but it is fat acids, obtained from various sources, which are solid at temperatures higher than ordinary room temperatures. The characteristics of the acids used in the various compounds are given in the table "Fat acids." Much difficulty was experienced in separating this small amount of organic material from such a large amount of inorganic, especially without oxidation or overheating.

	Compound No.—							
	29	30	31	32	33	34	35	36
Silica	3.74	0.74	0.59	0.33	1.11	10.22	0.43	0.32
Alumina	2.23	.62	.42	.19	.37	4.70	1.05	.....
Iron oxide	.61	.22	.18	.22	.45	.22	.21	.14
Lime	60.55	44.24	44.79	29.86	64.43	43.82	40.75	29.15
Magnesia	.86	29.91	30.54	20.56	.86	.70	26.54	21.07
Sodium oxide	2.42	Trace.	Trace.	Trace.	2.12	.34	.13	Trace.
Potassium oxide	.46	.00	.00	.00	.23	.70	.41	Trace.
Sulphuric anhydride	Trace.	Trace.	Trace.	Trace.	Trace.	1.32	.06	.60
Carbon dioxide	2.63	4.67	3.20	1.60	2.71	4.21	2.72	1.22
Total water	18.55	15.90	16.87	9.70	20.48	17.29	23.69	9.01
Paraffin	.....	.....	.....	.....	.....	.....	3.52	.....
Fat acids	7.98	3.20	3.30	37.73	6.99	16.20	.64	38.91
	100.03	99.50	99.89	100.19	99.75	99.72	100.15	100.42
Fat acids—								
Melting point °C	53.0	46.0	43.0	57.5	54.5	55.0	.....	56.1
Combining weight[5]	256	278	233	276	272	256	.....	258
Iodine figure	2.21	Trace.	Trace.	2.10	1.00	.....	.....	.....

[5] Compounds Nos. 29 and 33 combined with sodium and potassium; Compounds Nos. 30, 31, 32, and 33 combined with calcium.

(d) **Waterproofing Cements.**—Two waterproofing cements have been investigated. One of these was recommended especially as a coating, and has been already given under that division. The remarks given there apply here also. The analysis of the cement follows:

Compound No. 37

	Per cent
Silica	23.75
Alumina	5.96
Iron oxide	1.97
Lime	64.44
Magnesia	.91
Sulphuric anhydride	1.21
Sodium oxide	.11
Potassium oxide	.73
Ignition loss	1.07
	100.15

	Per cent
Carbon dioxide	0.52
Organic (fat acid)	.10
Water	.45

This is a cement to which a certain amount of water-repelling material has been added. As extracted, this consists of a potash soap of a mixed fatty acid. The quantity was so small that it could not be identified.

(e) **Active Liquid Fillers.**—There are three compounds in this class. The first is a coal-tar product, the volatile oils having been almost entirely removed. The tar would tend to bind together the particles of the cement and fill the voids. The exact nature of the chemical action which takes place, if any, is not known.

The second compound is a mixture of a semidrying fish oil with water glass. The former would tend to be slowly saponified by the lime of the cement; the latter would also form a lime silicate, in part. Both are much in excess, however, of all lime available.

Compound No. 38

Distillates:	Per cent
Up to 105° (water and ammonia, 48 per cent benzol, light oils)	2.50
105 to 210° (benzol, light oils; small quantity naphthalene)	3.20
210 to 240° (almost entirely naphthalene)	13.00
240 to 310° (heavy red oils containing a little naphthalene)	20.00
(Residue is a very hard brittle pitch.)	
Volatile at 105°	30.70
Free carbon	15.00
Ash	.40

Compound No. 39

	Per cent
Soap	1.05
Oil	47.29
Ash water glass (sodium silicate)	11.64
Volatile (water)	40.02
	100.00

The oil is a very offensive semidrying fish oil; specific gravity at 15° equals 0.9277; iodine figure, 163; saponification equivalent, 266; melting point of the fat acids, 36.5°C. It is menhaden oil.

The small amount of soap is a result of the combination of some of the free alkali of the water glass with the fish oil.

Compound No. 40

	Per cent
Silica	Trace
Alumina and iron oxide	0.25
Calcium chloride	27.19
Magnesium chloride	0.04
	27.48

(Remainder is water. Contains 0.15 per cent of a flocculent material which is an iron resinate (resin-shellac).

The calcium chloride in this material might form in the concrete an oxychloride cement. These, under certain conditions, have considerable value, but are not hydraulic, such as would be the case when used with a hydraulic cement for waterproofing purposes, as shown by the permeability tests. The value of the very small amount of iron resinate is unknown.

IX. OUTLINE OF TESTS OF DAMP-PROOFING AND WATERPROOFING MATERIALS

1. PERMEABILITY

Number of compound	Quaking-consistency mortar of 1 part Portland cement to—	Thickness of test piece in inches	Number of test pieces	Age in weeks when tested	Age in weeks when retested
0	4 parts sand	2	3	2	4,13,26
	....do	2	3	4	13,26
	....do	2	3	13	26
	....do	2	3	26	.....
	....do	2	3	2	4,13,26,52
	6 parts sand	2	3	2	4,13,26,52
	8 parts sand	2	3	2	4,13,26,52

1. PERMEABILITY—Continued.

Number of compound	Quaking-consistency mortar of 1 part Portland cement to—	Thickness of test piece in inches	Number of test pieces	Age in weeks when tested	Age in weeks when retested
0	4 parts sand	2	[7] 3	2	4,13,26,52
	6 parts sand	2	[7] 3	2	4,13,26,52
	8 parts sand	2	[7] 3	2	4,13,26,52
27–40	4 parts sand	2	[7] 3	2	4,13,26,52
	6 parts sand	2	[7] 3	2	4,13,26,52
	8 parts sand	2	[7] 3	2	4,13,26,52
23		2	3	2	4,13,26,52
41–45	4 parts sand	2	[7] 3	4	13,26,52

[7] Each.

2. ABSORPTION

Number of compound	Quaking-consistency mortar of 1 part Portland cement to—	Number of tests by weeks				Total tests
		4	13	26	52	
0	4 parts sand	3	3	3	3	12
	6 parts sand	3	3	3	3	12
	8 parts sand	3	3	3	3	12
27–40	4 parts sand	3	3	3	3	[8] 12
	6 parts sand	3	3	3	3	[8] 12
	8 parts sand	3	3	3	3	[8] 12
23				3	3	6
41–45	4 parts sand	3	3	3	3	[8] 12

[8] For each compound.

3. DAMP PROOFING

Compounds Nos. 27 to 40, inclusive, were incorporated in a 1–4, 1–6, and 1–8 quaking-consistency mortar. Three disk-shaped test pieces 7½ inches in diameter and 2 inches thick were made and tested for each mortar.

Compound No. 23 was made into similar disk-shaped test pieces of the same size and tested.

Compounds Nos. 1 to 26, inclusive, known as "coating compounds," were tested by applying them to the surface of disk-shaped test pieces 7½ inches in diameter and 2 inches thick of 1–4 mortar in which the sand passing a No. 20 sieve was removed so as to make the material more absorptive and present a more open surface. The coating was applied to one surface and entirely around the edge, the coated surface being exposed to water and

the opposite surface being covered by a moisture-indicating medium.

4. TENSION AND COMPRESSION

Number of compound	Quaking-consistency mortar of 1 part Portland cement to—	Number of each tension and compression test by weeks						Total tests
		1	2	4	13	26	52	
0	4 parts sand	3	3	3	3	3	3	36
	6 parts sand	3	3	3	3	3	3	36
	8 parts sand	3	3	3	3	3	3	36
27–40	4 parts sand	3	3	3	3	3	3	504
	6 parts sand	3	3	3	3	3	3	504
	8 parts sand	3	3	3	3	3	3	504
23		3	3	3	3	3	3	36
41–45	4 parts sand	3	3	3	3	3	3	180

X. LABORATORY EQUIPMENT USED IN WATERPROOFING TESTS

The general equipment and apparatus used in these tests was the same as described in Part I, with the following additional apparatus: Tension briquette molds, 2-inch cube molds, and glass pallets, as shown in Fig. 8; a 10 000-pound capacity compression testing machine, as shown in Fig. 25; a 40 000-pound capacity hydraulic pressure compression testing machine, as shown in Fig. 26; and a 1000-pound capacity briquette-testing machine.

XI. DESCRIPTION OF TESTS OF DAMP-PROOFING AND WATERPROOFING MATERIALS

1. PROPORTIONS

All batches were computed and computations checked in a record book previous to mixing, the proportions being by volume, but were converted into weight measure for greater accuracy as fully described in Part I.

2. CONSISTENCY

Only one consistency was used, which has been designated as a quaking consistency which, when molded into a ball with the hands, would adhere when held between the thumb and finger,

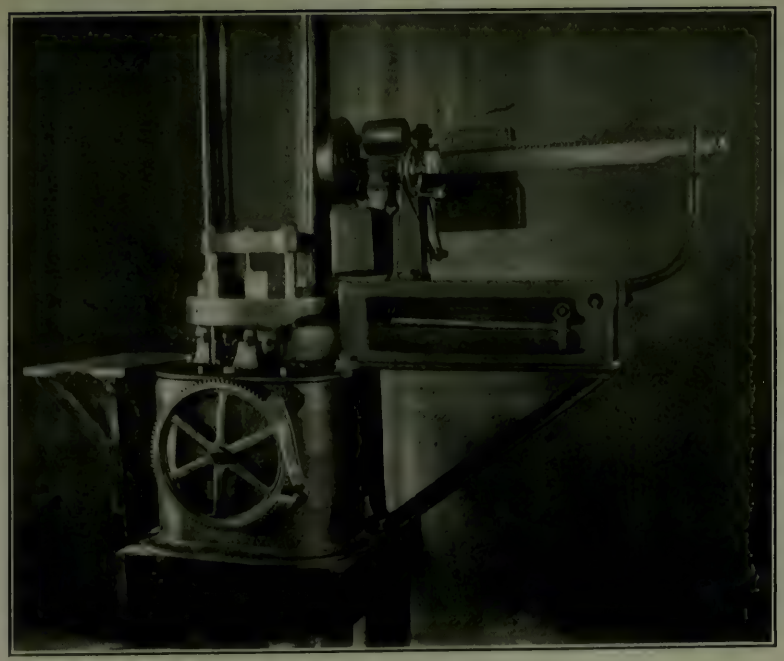

Fig. 25.—*10,000-pound Capacity Compression Testing Machine.*

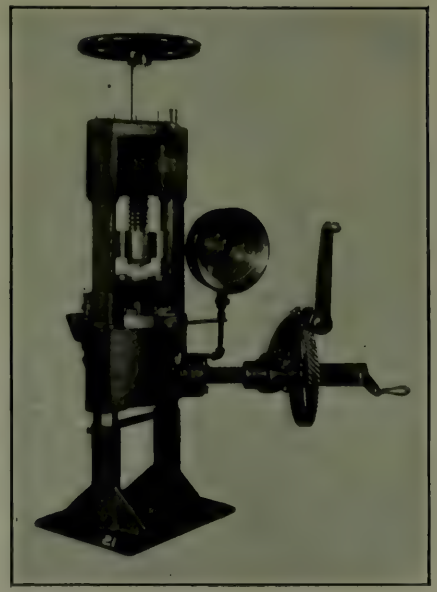

Fig. 26.—*40,000-pound Capacity Hydraulic Pressure Compression Testing Machine.*

but which would not do so with the addition of any more water. The percentage of water required in terms of total dry weight of sand and cement was predetermined for each mortar and kept the same throughout the series regardless of the addition of compounds which might cause a slightly drier resultant. Water could easily be brought to the surface with a trowel.

3. MIXING

Three permeability test pieces, 12 absorption test pieces, 18 compression test pieces, and 18 briquettes were all molded from one batch so as to insure like conditions. The mixing was done by hand in a manner as fully described in Part I, page 15. The damp-proofing test pieces were molded separately, three in a batch.

The recommendations of the manufacturers were followed in proportioning and incorporating the integral compounds. It was found that any mortar richer in cement than a 1–4 proportion was impervious in itself under a hydrostatic pressure of 20 pounds to the square inch; thus even though some manufacturers stated that their compound must be incorporated into a 1–2 or a 1–3 proportion of mortar, their wishes must obviously be disregarded in this respect.

The quantity of each compound incorporated in the mortars and the method of incorporating is given in accompanying table:

Integral Compounds, Quantity Used, and Manner of Incorporating

No. of compound.	Quantity of each compound used.	Manner of incorporating in mortar.
	Grams compound to grams cement.	
[9] 23		
27	2–100	Mixed with dry cement before mixing with sand and water.
27*b*	10–100	Do.
28	5–100	Do.
29	2–100	Do.
30	2–100	Do.
31	2–100	Do.
32	2–100	Do.
33	2–100	Do.

Integral Compounds, Quantity Used, and Manner of Incorporating—Con.

No. of compound.	Quantity of each compound used,	Manner of incorporating in mortar.
	Grams compound to grams cement.	
34	25–1000	Mixed with dry cement before mixing with sand and water.
35	1–100	Do.
36	2–100	Do.
[10] 37		
38	5–100	Mixed with dry sand and cement.
	Cubic centimeters liquid compound to cubic centimeters water.	
39	416–10000	This mixture was used as the mixing water.
40	10–100	Do.
	Grams compound to grams cement.	
[11] 41	13–100	Mixed with dry cement.
[11] 42	16–100	Do.
[11] 43	16–100	Do.
[11] 44	20–100	Do.
[11] 45	22–100	Do.

[9] This is a waterproofed cement mortar and was tested as received.
[10] This is a waterproof cement, and it was substituted in place of all of the Portland cement.
[11] These materials are all so proportioned that, assuming the weight of cement at 100 pounds per cubic foot (1.60 grams per cubic centimeter), the compound is 20 per cent by volume of the cement. The relative weights in grams per cubic centimeter are as follows: 41=1.04, 42=1.28, 43=1.28, 44=1.65, and 45=1.75.

4. MOLDING

a. PERMEABILITY TEST PIECES

The molds for these test pieces were made from wrought-iron well casing, 7½ inches in diameter, cut into sections 2 inches in length. They were painted white on the outside and marked with the test number when filled.

The empty molds were wetted on the inside and were placed three in a set on a board which had an oiled galvanized-iron top. The mold was filled in three operations, each layer being thoroughly and systematically tamped with a 1-pound peen-shaped tamper, and the top struck off level with the edge of a trowel, the surface being left rough. After storage for 24 hours in the moist closet both the top and bottom surfaces were brushed with

a wire brush which removed any thin "skin" of cement which may have been brought to the surface, making the surface rough and homogeneous with the mass. The iron mold was not removed from the test piece till the test was completed.

b. DAMP-PROOFING TEST PIECES

The damp-proofing test pieces were of the same size and shape as the permeability test pieces, but they were molded in heavy galvanized-iron molds which could be opened and removed from the test piece immediately after molding. These test pieces were tamped and leveled off in the same manner as the permeability test pieces, but the mortars containing compounds to be tested were mixed with a slightly less amount of water so that the molds could be removed immediately. The surfaces of those test pieces made with coarse sand, which were to be coated, were not brushed with a wire brush, as the surface was rough and porous. The test pieces were stored in the damp room.

c. ABSORPTION TEST PIECES

These were 2-inch cubes, molded in three-gang brass molds, illustrated in Fig. 8. The mold was filled and the material pressed into place with the thumbs and thoroughly compacted and troweled. The mold was then turned over on a glass plate and the other surface compacted and troweled. The test pieces were stored in the moist closet for 24 hours, the molds removed, and the test pieces stored on shelves in the damp room until tested.

d. COMPRESSION TEST PIECES

These were of the same size and shape as the absorption test pieces and were made in the same molds and manner as above described.

e. TENSION TEST PIECES

The molds for these test pieces were the standard five-gang tension briquet molds illustrated in Fig. 8. The material was pressed into place with the thumbs, the mold being turned and both surfaces compacted and troweled. After 24 hours' storage in the moist closet the molds were removed and the test pieces were stored in the damp room.

5. STORAGE

All test pieces were stored on shelves in the damp room illustrated in Fig. 9, between the time of molding and testing, and were sprinkled three times each 24 hours.

6. TESTING

a. PERMEABILITY TEST PIECES

The permeability test pieces were brought from the damp room on the morning of the day when they were to be tested, placed in the test-piece holder, connected to the pipe rack, and the test was conducted in the same manner as described in Part I. The piping was so arranged that two sets of tests at different water pressures could be conducted at the same time.

b. DAMP-PROOFING TEST PIECES

The damp-proofing test pieces having compounds incorporated were brought from the damp room when 21 days old and permitted to surface dry in the air for from 4 to 6 days, when a round filter paper 6 inches in diameter was secured to one surface with a thin wheat-flour paste, the filter paper being struck with the palm of the hand, so that it conformed to the roughness of the surface as shown in Fig. 27. The filter paper was now painted with an alcoholic solution of phenol-phthalein, which turns pink in the presence of alkaline water. The test piece was placed, filter-paper side up, in a trough of water one-half inch deep on the morning of the twenty-eighth day. The test piece being 2 inches thick and the water in which it was placed only one-half inch deep, if moisture was absorbed by the material to the upper surface it carried with it enough alkali from the cement to indicate the moisture on the filter paper. An examination of the specimen was made every hour for the first 8 hours and once every 24 hours thereafter.

The damp-proofing test pieces to be coated were brought from the damp room when 6 days old and allowed to thoroughly surface dry in the air which required from 4 to 6 days, when one surface and the entire edge was given the first coat of compound in the manner prescribed by the manufacturer. After permitting this

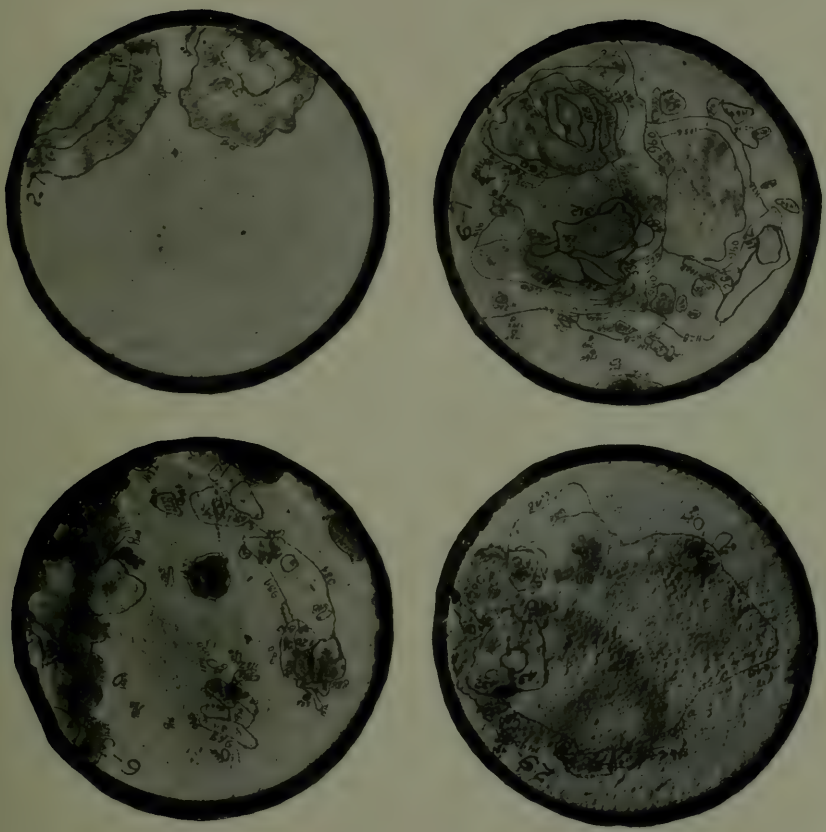

Fig 27 —*Damp-proofing Test Pieces.*

to dry for the period as specified by the manufacturer, the second coat was applied. Two coats of each compound were applied, although some manufacturers stated that one coat would be sufficient. On the twenty-first day after molding the filter paper was applied, the test piece placed in the trough of water when 28 days old, and the test conducted as described above. Of course, the slightest break in this coating would permit the moisture to enter and, by capillarity, be carried to the upper surface. Some test pieces which did not fail in the half-inch depth of water were placed in a trough in which the water was 1 inch deep. These are indicated with the period of exposure, in the tables.

c. ABSORPTION TEST PIECES

These were brought from the damp room on the day when tested, weighed to one five-hundredth of a gram and immersed so that the top surface was 3 inches below the surface of the water. The test pieces brought from the damp room when 28 days old were immersed for a period of 28 days previous to drying, when they were weighed. However, the gain in weight after this 28-day immersion was found to be less than 1 per cent of the original weight when first taken from the damp room, showing that the test pieces had absorbed nearly the maximum amount of water in the damp room. Hence, the test pieces tested at subsequent periods, 13, 26, and 52 weeks, were immersed for only 7 days instead of 28 days, previous to drying.

After this initial immersion the test pieces were placed in an oven the temperature of which was maintained between 100° and 110° C. (212° to 230° F.), where they were dried, being weighed twice each day until they showed no further loss in weight, which required about six days. They were taken from the oven and allowed to cool slowly in the air until the following day, when they were again immersed to the same depth as the first immersion. The test pieces were taken from the water and weighed after 1, 3, 7, 14, and 28 days' immersion. The purpose of this long immersion was to give the compound time to leach out and lose any antipathetic properties it might have. The test pieces tested at the 26-week period were also weighed after 30 minutes' immersion.

d. COMPRESSION TEST PIECES

The 2-inch cubes, upon which the compressive strength was determined, were tested in the 10 000-pound hand-power testing machine, or test pieces requiring more than 10 000 pounds total load were tested in the 40 000-pound hydraulic testing machine. Practically all test pieces gave a theoretical break forming a cone top and bottom.

e. TENSION TEST PIECES

The tension briquettes were tested on a standard testing machine. A little trouble was experienced in testing the very lean mixtures in that they would break in the grips, but the greatest care was observed and results are uniform and comparable.

XII. RESULTS OF TESTS

1. COMPUTATIONS

a. PERMEABILITY TESTS

The quantity of water flowing through the permeability test pieces for one minute at each period when a reading was taken was recorded.

The cubic centimeters of water passed per minute per square centimeter of surface was computed by dividing the total quantity of water passed through the test piece in one minute by its area in square centimeters (126.68). Only this computed result is reported in the accompanying tables, and an average is taken for each three similar specimens. Where there was no measurable flow or drip but the exposed surface continued to remain moist, showing that some water was penetrating, it is recorded in the tables as "moist." Readings recorded in the tables as zero indicate that no moisture whatever appeared on the exposed undersurface.

b. DAMP-PROOFING TESTS

There were no computations on these tests, but the observed results of the test are reported directly in the tables. In Fig. 10 is shown in detail four test pieces which have failed and are typical of all failures.

c. ABSORPTION TESTS

The absorption in terms of the weight and volume is computed from the recorded results in the manner as stated in Part I, page 18.

d. COMPRESSION TESTS

The compression test pieces being 2-inch cubes, had a total sectional area of 4 square inches underload; thus the ultimate strength in pounds per square inch was obtained by dividing the total load by 4. Only a summary of this computed value is reported in the tables.

e. TENSION TESTS

The tension briquettes have a sectional area of 1 square inch; so that the total breaking load is in pounds per square inch, and a summary is reported directly in the tables without computation.

2. TABULATED RESULTS AND DIAGRAMS

It will be observed that the quantity of water passing through the test pieces in some cases is very small; especially is this so with the 1 : 4 proportion mortars. From the appearance of the lower surface the water comes through evenly, collecting on the lower surface and finally dripping.

One drop under these conditions was found to be equal to approximately one-tenth of a cubic centimeter, and this divided by the exposed area, 126.68 square centimeters, is 0.0008 cubic centimeter or 0.8 cubic millimeter per square centimeter of exposed surface. Thus it will be seen that although three similar test pieces may apparently seem to be widely divergent in permeable qualities, in reality they are not, and as a whole the tests are very regular and uniform. The comparative results are also shown diagrammatically.

Tables 11 and 12 (Figs. 28 and 28a).—The untreated mortar is slightly permeable at all ages, but the permeability decreases with the continuation of the flow at the earlier periods. In the later tests it will be observed that the flow is about the same at the end of the seventh or twenty-fourth hour as at the first hour. This decrease in flow at the two and four week tests is probably due to a silting up of the mortar, the water loosening up small particles and carrying them into and filling up the pasageways.

In comparing the results of tests on untreated mortars of Part II with similar mortars of Part I, it will be observed that those of Part II are the more permeable, which may be explained by the fact that the surfaces of the test pieces of Part I were not brushed with

a wire brush soon after molding, as were those of Part II, and after a period of several weeks this surface became so hard it was prac-

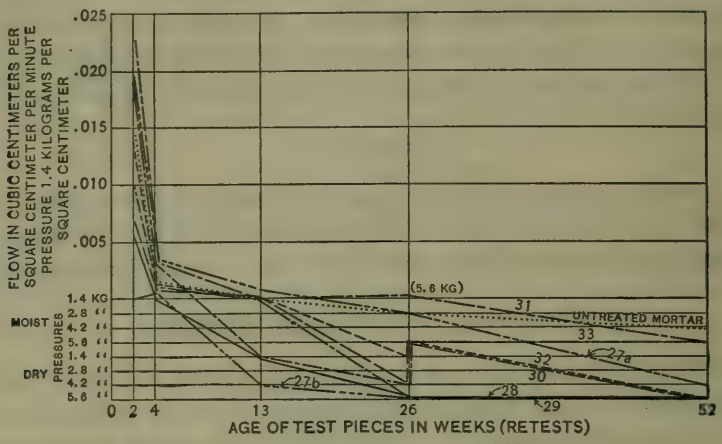

Fig. 28.—*Permeability of Waterproofed Mortars.*

One part Portland cement to 4 parts No. 1 sand.

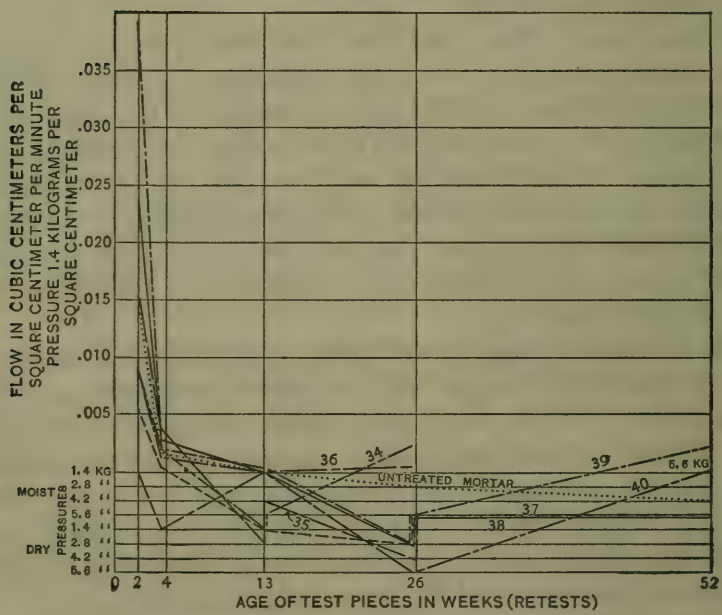

Fig. 28a.—*Permeability of Waterproofed Mortars.*

One part Portland cement to 4 parts No. 1 sand.

tically impossible to clean the surface so effectively with a wire brush. Compare with Table 17.

Compound No. 32.—The value of the addition of this compound is not apparent until the 13-week test. At 26 and 52 weeks it is somewhat less permeable than the untreated mortar. However, it is a question as to whether this more impermeable quality is not due to the fact that the added material simply furnished more fine particles for closing up the voids. If its greater impermeability is due to the "water-repelling" qualities of the compound, it should have been as effective at the two-week test as at later tests.

Compound No. 31.—The value of this compound is slightly apparent at the 26-week period, and to some extent at the 13 and 52 week periods, but not so markedly as the previous compound. It is peculiar how the individual test pieces vary; at 13 weeks No. 1 was permeable and No. 2 was not; at 26 weeks conditions were reversed; and at 52 weeks they were again reversed.

Compound No. 33.—The addition of this material had very little effect on the permeability of the mortar. However, it was more impermeable after the four-week period than the untreated mortar.

Compound No. 30.—The result of the addition of this compound was about the same as 32, showing a marked decrease in permeability after the four-week tests.

Compound No. 29.—The apparent value of the addition of this material has been delayed until the 26-week test, after which test pieces were much less permeable than the plain mortars.

Compound No. 28.—The value of this compound is evident from the earliest test and continues to the 52-week test. Its value, however, can probably be attributed to the large quantity (5 per cent) used, which simply as inert void-filling material would be expected to yield the results obtained. Compare with 27b.

Compound No. 27a.—The reason for the greater permeability at the early period of these test pieces containing 2 per cent of the inert filler, hydrated dolomitic lime, is not apparent. From this test it would seem that the fatty repelling substance in the above compounds is of considerable value if only a small quantity of inert material is used, but from the succeeding test it will be observed that the same or even greater beneficial results can be obtained by the addition of a larger percentage of the inert material.

Compound No. 27b.—This is the most efficient medium employed and resulted in an almost impermeable mortar at the two-week

test. Its value is probably due to its void-filling properties and the same results could be expected from any other finely ground inert material, such as sand, clay, etc.

Compound No. 37.—It is slightly less permeable than the untreated mortar, but its value is not apparent until the 13-week test. Since this is simply a cement with the repelling substance added and it was used in the same proportion as the Portland cement used in the untreated mortar, it would seem that either the cement was of different quality or the fatty repellent substance plays a part and is beneficial.

Compound No. 40.—The addition of this material has affected the mortar and made it much more impermeable; in fact, at four weeks it is the most impermeable of any of the mortars. This may be explained by the fact that the addition of the compound made the mixture of wetter consistency; but it seems to be very irregular, for at 13 weeks and 52 weeks it seems to lose its impermeable qualities slightly.

Compound No. 39.—These tests indicate that the addition of the compound is not markedly beneficial.

Compound No. 38.—The mortar treated with this compound has little value over the untreated mortar in so far as its permeable qualities are concerned.

Compound No. 34.—The addition of this compound somewhat decreased the permeability, which, however, was not apparent until the 13-week test. This compound is very similar to 32, as it contains a very large percentage of repellent substance. The cause of the failure of two of the test pieces at the 26-week period is not known.

Compound No. 35.—The value of the addition of this compound was apparent at the 13-week period, and continued so through the 26-week test. It is peculiar that these specimens should be so impermeable, considering the fact that only 1 per cent of the compound was added.

Compound No. 36.—The addition of this compound only slightly affected the permeability.

Compound No. 23.—This test can not be directly compared with the others, as it is practically a test on a 1–3 proportion mortar. (See analysis.)

Tables 13 and 14 (Figs. 29 and 29a).—In these tests it will be observed that the value of the addition of the compounds was not

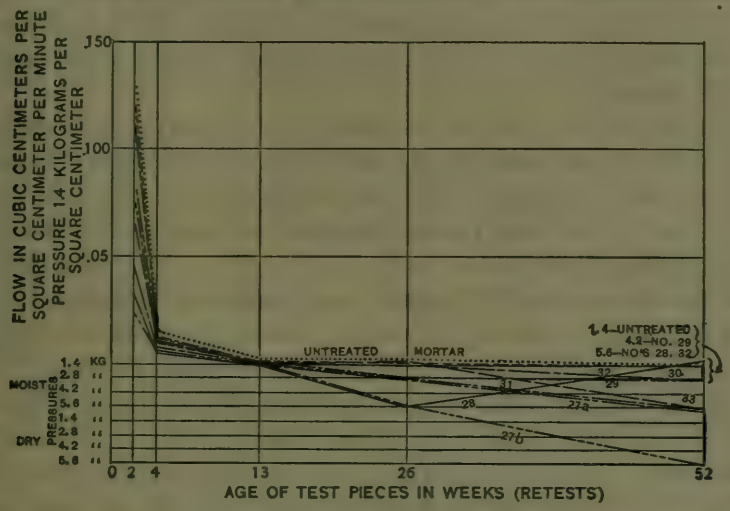

Fig. 29.—*Permeability of Waterproofed Mortars.*

One part Portland cement to 6 parts No. 1 sand.

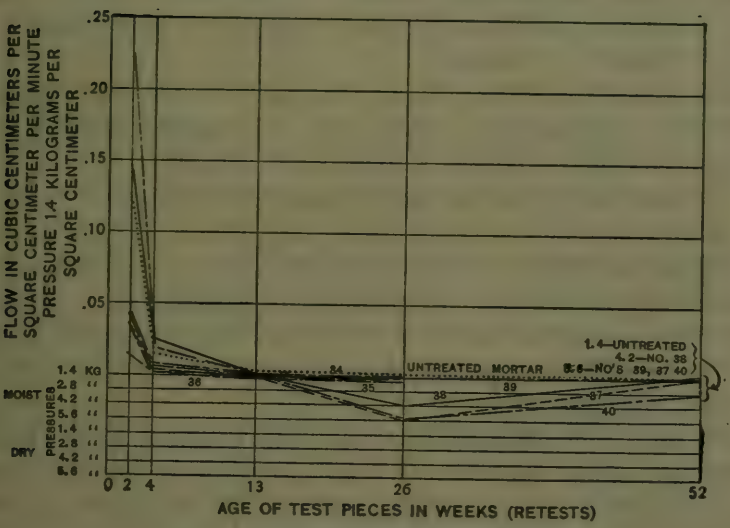

Fig. 29a.—*Permeability of Waterproofed Mortars.*

One part Portland cement to 6 parts No. 1 sand.

apparent in most cases until the 26-week period, and some of the compounds which were somewhat effective in the 1–4 mixture were

not at all effective in the 1–6 mixture. The efficiency of 2 per cent of inert hydrated dolomitic lime filler is apparently as great as that of any of the water-repelling compounds in this mortar. Compound No. 27b was the most effective waterproofing medium in this mortar.

The permeability decreased with the continuation of the flow at the two and four week tests, but not at later periods; in fact, in several cases it increased with the continuation of the flow. However, most of the test pieces decreased in permeability with age.

Comparing these tables with Table 1, Part I, it will be noted that the test pieces of the latter were the more impermeable, which may be explained by the fact that the test pieces in Part II were brushed with a wire brush while the cement was still green. Those of Part I were brushed after the cement had acquired a hard set.

Tables 15 and 16 (Figs. 30 and 30a).—The addition of the compounds to this lean mortar had no effect in any case on the permeability up to the 26-week period. At the 52-week period several of the mortars containing compounds are slightly less permeable than the untreated mortar, but not to any decided degree. As a whole, the addition of so small a quantity of compound to so lean a mixture is valueless.

The quantity of water passing through the test piece decreased with the continuation of flow, but to a greater extent at the earlier tests than at the 26 and 52 week periods.

The permeability of mortar decreased with its age.

Compared with the 1–6 mortar, the 1–8 mortar was as impermeable at 4 weeks as the 1–6 mortar was at 2 weeks, and at 52 weeks both mortars have the same permeability. Compared with the 1–4 mortar, the 1–8 mortar is as impermeable at 52 weeks as the 1–4 mortar is at 13 weeks. These comparisons are between the untreated mortars.

Table 17.—The purpose of these tests was to show the effect of retesting, that is, the value of a test piece which had been tested at an earlier age as compared with one of the same age which had not been previously tested.

Since this was a 1–4 mortar, Nos. 1, 2, and 3 should be directly comparable with the untreated mortar of Table 11, and the result of the tests should be, and are, similar.

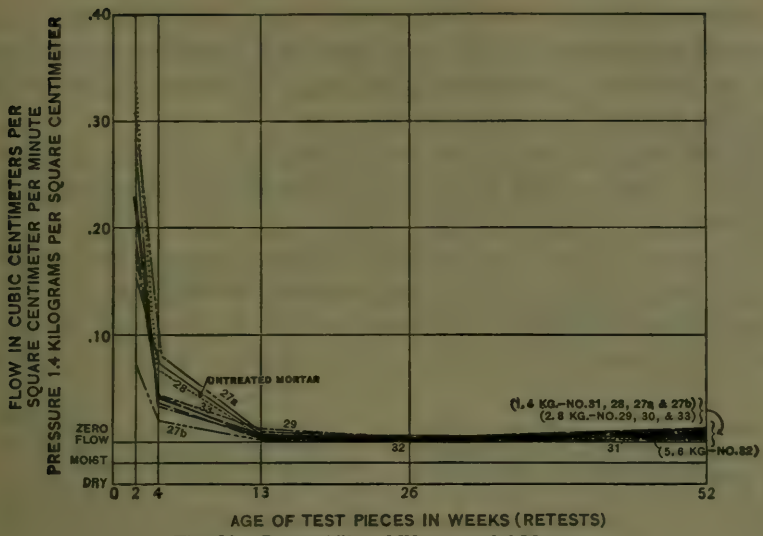

Fig. 30—*Permeability of Waterproofed Mortars.*

One part Portland cement to 8 parts No. 1 sand.

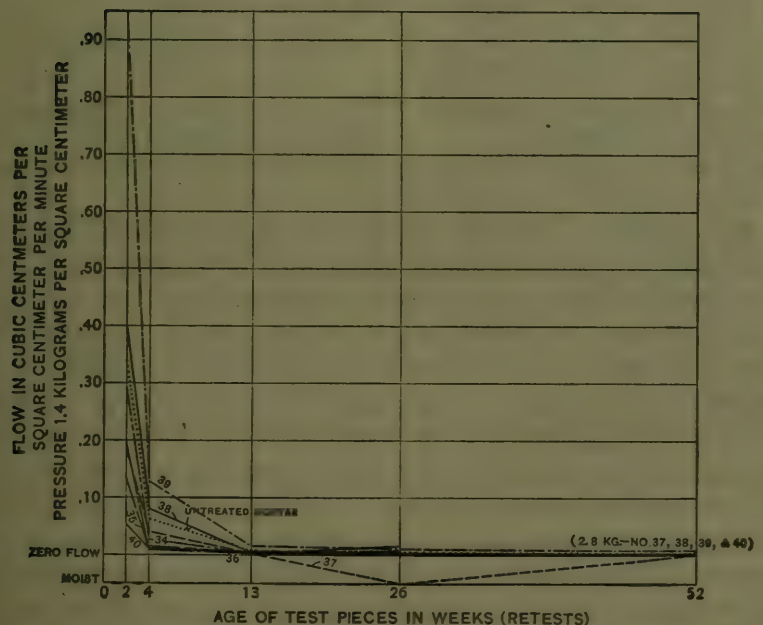

Fig. 30a.—*Permeability of Waterproofed Mortars.*

One part Portland cement to 8 parts No. 1 sand.

Comparing the tests with the retests—at 4 weeks they were both practically the same; at 13 weeks there was also little or no difference; at 26 weeks the retested test pieces were more impermeable than the original test pieces at this age.

All test pieces become more impermeable with age and also slightly less permeable with the continuation of the flow at the early ages.

Table 18.—All the fillers are quite effective, but the clays appear to be slightly more effective than the sand or feldspar.

Table 19.—The value, for damp-proofing purposes, of the addition of compounds to a 1–4 mortar mixture is evident from the

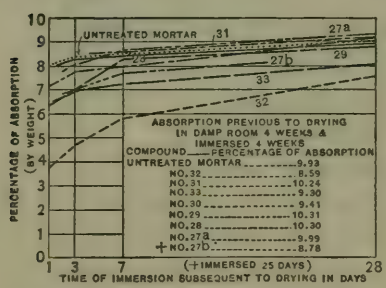
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
31
27a
27b
29
33
32
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 4 WEEKS & IMMERSED 4 WEEKS
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 9.93
NO. 32 ..... 8.59
NO. 31 ..... 10.24
NO. 33 ..... 9.30
NO. 30 ..... 9.41
NO. 29 ..... 10.31
NO. 28 ..... 10.30
NO. 27a 9.99
+ NO. 27b 8.78
1 3 7 (+IMMERSED 25 DAYS) 28
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 31.—*Absorption of Waterproofed Mortars.*

Age 4 weeks—1 part Portland cement to 4 parts No. 1 sand.

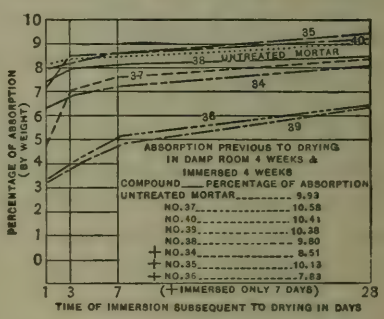
PERCENTAGE OF ABSORPTION (BY WEIGHT)
35
40
38
UNTREATED MORTAR
37
34
36
39
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 4 WEEKS & IMMERSED 4 WEEKS
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 9.93
NO. 37 ..... 10.58
NO. 40 ..... 10.41
NO. 39 ..... 10.38
NO. 38 ..... 9.80
+ NO. 34 ..... 8.51
+ NO. 35 ..... 10.13
+ NO. 36 ..... 7.83
1 3 7 (+IMMERSED ONLY 7 DAYS) 28
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 31a.—*Absorption of Waterproofed Mortars.*

Age 4 weeks—1 part Portland cement to 4 parts No. 1 sand.

result recorded in the table. It will be observed that all the mortars containing water-repelling compounds were damp proof; also the mortar containing 10 per cent of the inert hydrated lime filler, but the mortar containing only 2 per cent of the hydrated lime failed. Compound No. 38, which showed little or no value in the permeability tests, also does not seem to be effective in this test.

This damp-proofing test of itself should not condemn these materials, as all damp-proofing compounds are not expected to stand constant exposure to water. The tests were made to furnish comparable data, and it is believed that they have served the purpose. In the lean mortars the results were more striking, in that several of the compounds were unquestionably effective to a marked degree and the inert filler failed. The same compounds which were the most effective in the permeability tests were the most effective in these tests with one or two exceptions.

Considering the damp-proofing tests as a whole, several of the compounds were effective, but it would also seem that the same effective and possibly a more positive result can be obtained more

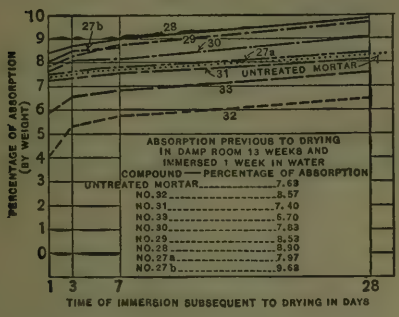
PERCENTAGE OF ABSORPTION (BY WEIGHT)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 13 WEEKS AND IMMERSED 1 WEEK IN WATER
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 7.63
NO. 32 8.57
NO. 31 7.40
NO. 33 6.70
NO. 30 7.83
NO. 29 8.52
NO. 28 8.30
NO. 27a 7.97
NO. 27b 9.62
UNTREATED MORTAR

Fig. 32.—*Absorption of Waterproofed Mortars.*

Age 13 weeks—1 part Portland cement to 4 parts No. 1 sand.

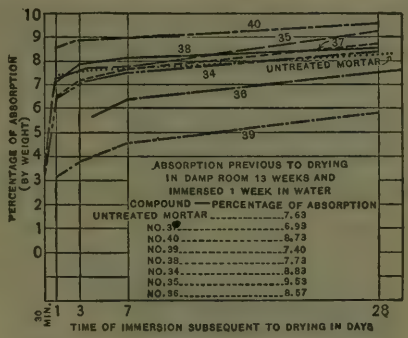
PERCENTAGE OF ABSORPTION (BY WEIGHT)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 13 WEEKS AND IMMERSED 1 WEEK IN WATER
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 7.63
NO. 37 6.93
NO. 40 6.73
NO. 39 7.40
NO. 38 7.73
NO. 34 8.83
NO. 35 9.53
NO. 36 8.57
UNTREATED MORTAR

Fig. 32a.—*Absorption of Waterproofed Mortars.*

Age 13 weeks—1 part Portland cement to 6 parts No. 1 sand.

economically by using sufficient cement and correct proportioning of the materials entering into the mortar or concrete and thus obtaining a maximum density.

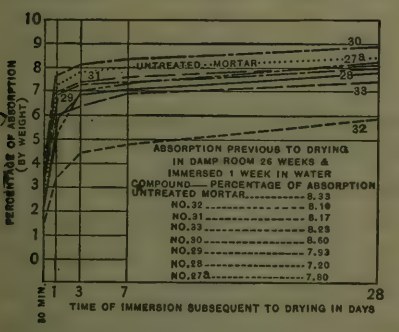
PERCENTAGE OF ABSORPTION (BY WEIGHT)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 26 WEEKS & IMMERSED 1 WEEK IN WATER
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 8.33
NO. 32 8.10
NO. 31 8.17
NO. 33 8.23
NO. 30 8.50
NO. 29 7.93
NO. 28 7.20
NO. 27a 7.80
UNTREATED MORTAR

Fig. 33.—*Absorption of Waterproofed Mortars.*

Age 26 weeks—1 part Portland cement to 4 parts No. 1 sand.

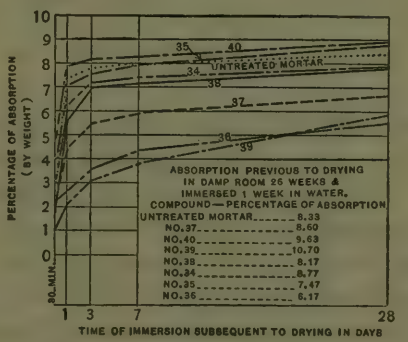
PERCENTAGE OF ABSORPTION (BY WEIGHT)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 26 WEEKS & IMMERSED 1 WEEK IN WATER.
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 8.33
NO. 37 8.60
NO. 40 9.63
NO. 39 10.70
NO. 38 8.17
NO. 34 8.77
NO. 35 7.47
NO. 36 6.17
UNTREATED MORTAR

Fig. 33a.—*Absorption of Waterproofed Mortars.*

Age 26 weeks—1 part Portland cement to 4 parts No. 1 sand.

Table 20 (Figs. 31, 31a, 32, 32a, 33, 33a, 34, 34a.).—The results of the absorption tests are very uniform; in fact much more so than had been expected.

The moisture contained in the test pieces after storage in the damp room and immersion previous to drying, was the same

in almost every case regardless of the compound incorporated. The absorption after drying, however, varies with the different compounds. In some cases the absorption is very slow at first, but after the 28 days' immersion they all have approximately the same absorption, with a few exceptions.

The inert filler seems to have very little or no effect on the absorption at any time.

Comparing with the results of 4 and 13 week tests, it will be observed in the 26-week tests that the absorption after drying, of

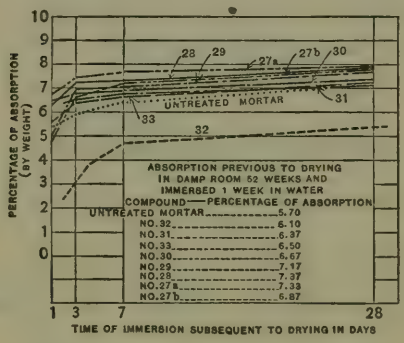

Fig. 34.—*Absorption of Waterproofed Mortars.*

Age 52 weeks—1 part Portland cement to 4 parts No. 1 sand.

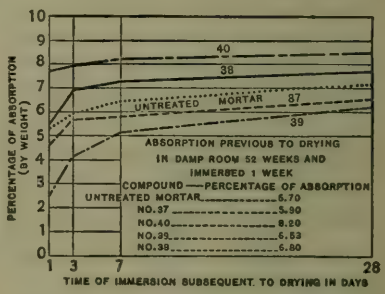

Fig. 34a.—*Absorption of Waterproofed Mortars.*

Age 52 weeks—1 part Portland cement to 4 parts No. 1 sand.

the mortars having compounds incorporated have decreased much more rapidly with age than the untreated mortars.

At the 52-week period it would seem that most of the treated mortars had lost their increased effectiveness, not that they have increased any in absorption over the 26-week tests but that the untreated mortar has decidedly decreased in absorption between the 26 and 52-week period and is now as low as the treated mortars. In fact, previous to drying, the untreated mortar is even less absorptive than the treated mortars.

The rate of absorption after drying, however, was less in several cases for the treated mortars than for the untreated mortar.

The absorption has decreased with the age of the mortar in every case.

Table 21 (Figs. 35, 35a, 36, 36a, 37, 37a, 38, 38a).—The value of the addition of the compounds was not as apparent in

this leaner mortar. The total absorption before drying was practically the same in every case, irrespective of the addition of the compound, but the rate of the absorption after drying was

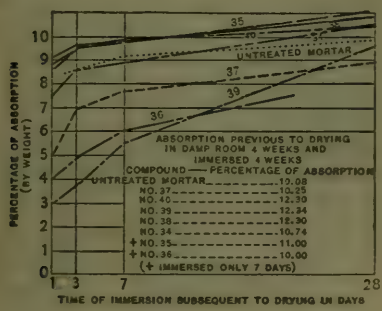
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 4 WEEKS AND IMMERSED 4 WEEKS
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 10.08
NO. 37 10.25
NO. 40 12.30
NO. 39 12.34
NO. 38 12.30
NO. 34 10.74
+ NO. 35 11.00
+ NO. 36 10.00
(+ IMMERSED ONLY 7 DAYS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 35.—*Absorption of Waterproofed Mortars.*

Age 4 weeks—1 part Portland cement to 6 parts No. 1 sand.

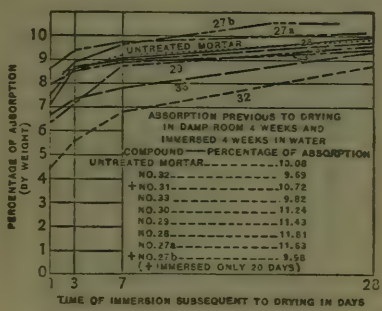
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 4 WEEKS AND IMMERSED 4 WEEKS IN WATER
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 10.08
NO. 32 9.69
+ NO. 31 10.72
NO. 33 9.82
NO. 30 11.24
NO. 29 11.43
NO. 28 11.81
NO. 27a 11.63
+ NO. 27b 9.58
(+ IMMERSED ONLY 20 DAYS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 35a.—*Absorption of Waterproofed Mortars.*

Age 4 weeks—1 part Portland cement to 6 parts No. 1 sand.

much slower in several cases in which the compound was incorporated, than with the untreated mortar. The inert filler is again practically valueless. After 28 days' immersion subsequent to the drying, all compounds have practically lost their effectiveness and the absorption is nearly the same as that of the untreated mortar.

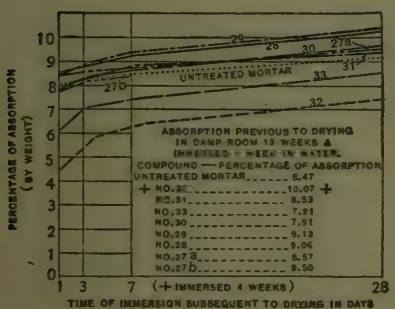
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 13 WEEKS & IMMERSED 1 WEEK IN WATER.
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 8.47
+ NO. 32 10.07 +
NO. 31 8.53
NO. 33 7.81
NO. 30 7.91
NO. 29 9.13
NO. 28 9.06
NO. 27a 8.57
NO. 27b 9.50
(+ IMMERSED 4 WEEKS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 36.—*Absorption of Waterproofed Mortars.*

Age 13 weeks—1 part Portland cement to 6 parts No. 1 sand.

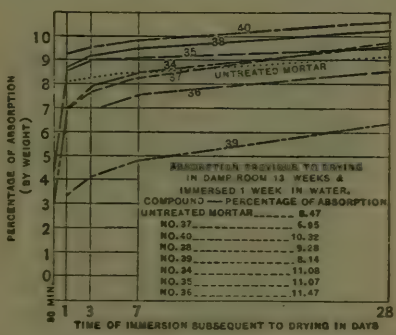
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
IN DAMP ROOM 13 WEEKS & IMMERSED 1 WEEK IN WATER.
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 8.47
NO. 37 6.95
NO. 40 10.32
NO. 38 9.28
NO. 39 8.14
NO. 34 11.08
NO. 35 11.07
NO. 36 11.47
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 36a.—*Absorption of Waterproofed Mortars.*

Age 13 weeks—1 part Portland cement to 6 parts No. 1 sand.

Comparing the 13-week tests with the 4-week tests, it will be observed that the absorption after drying at the end of 28 days is only slightly less at 13 weeks than at 4 weeks.

In the 26-week tests the rate of absorption after drying is slightly less in the case of some of the mortars containing compounds, but the absorption before drying is approximately the same in every

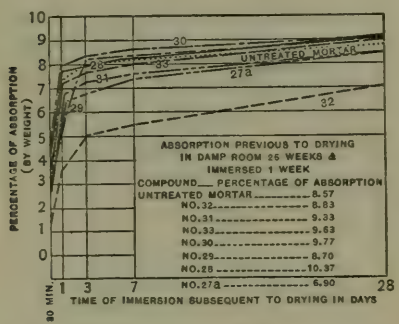

Fig. 37.—*Absorption of Waterproofed Mortars.*

Age 26 weeks—1 part Portland cement to 6 parts No. 1 sand.

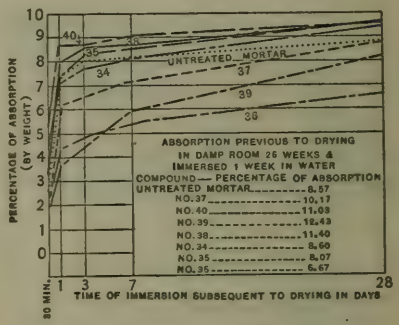

Fig. 37a.—*Absorption of Waterproofed Mortars.*

Age 26 weeks—1 part Portland cement to 6 parts No. 1 sand.

case. Also at 28 days after drying the absorption is practically the same with the treated as with the untreated mortar, with one or two exceptions.

At the 52-week period several of the treated mortars still show a slower rate of absorption after drying than the untreated mortar,

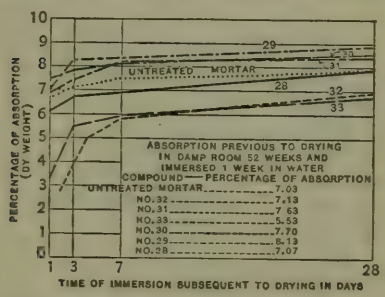

Fig. 38.—*Absorption of Waterproofed Mortars.*

Age 52 weeks—1 part Portland cement to 6 parts No. 1 sand.

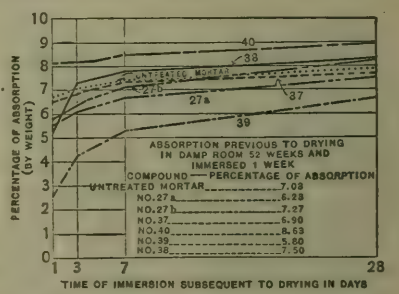

Fig. 38a.—*Absorption of Waterproofed Mortars.*

Age 52 weeks—1 part Portland cement to 6 parts No. 1 sand.

but as in the previous earlier tests the absorption previous to drying was practically the same for the treated mortars as for the untreated mortar.

The absorption has decreased slightly with the age of the mortar.

Table 22 (Figs. 39, 39a, 40, 40a, 41, 41a, 42, 42a).—In the 4-week tests, previous to drying, the absorption is practically the same for the treated as for the untreated mortar. The rate of absorption after drying is practically the same for both in all but

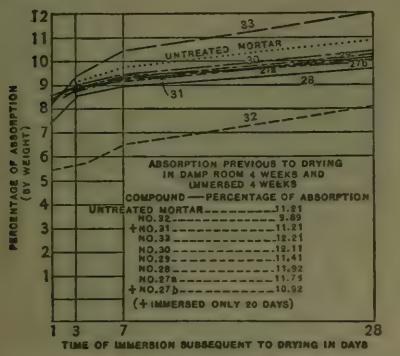
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 4 WEEKS AND IMMERSED 4 WEEKS
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 11.21
NO. 32 9.89
+NO. 31 11.21
NO. 33 12.21
NO. 30 12.11
NO. 29 11.41
NO. 28 11.92
NO. 27a 11.75
+NO. 27b 10.92
(+ IMMERSED ONLY 20 DAYS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 39.—*Absorption of Waterproofed Mortars.*

Age 4 weeks—1 part Portland cement to 8 parts No. 1 sand.

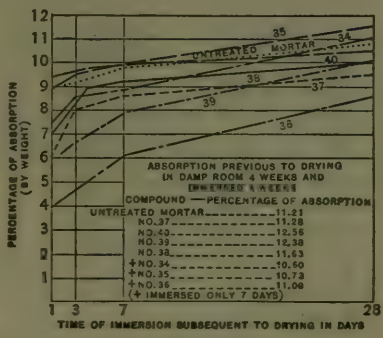
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 4 WEEKS AND IMMERSED 4 WEEKS
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 11.21
NO. 37 11.28
NO. 40 12.56
NO. 39 12.38
NO. 38 11.63
+NO. 34 10.50
+NO. 35 10.73
+NO. 36 11.06
(+ IMMERSED ONLY 7 DAYS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 39a.—*Absorption of Waterproofed Mortars.*

Age 4 weeks—1 part Portland cement to 8 parts No. 1 sand.

one or two cases. The effect of the addition of the compound is marked, however, in these several exceptions.

Comparing with Table 20, it will be observed that the lean mortar is slightly more absorptive than the richer 1–4 mortar.

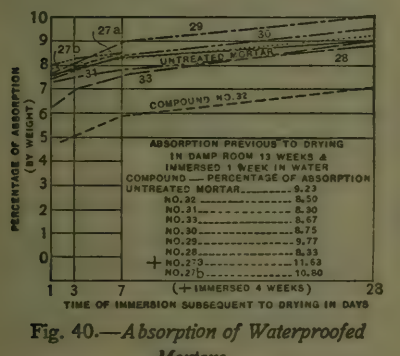
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
COMPOUND NO. 32
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 13 WEEKS & IMMERSED 1 WEEK IN WATER
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 9.23
NO. 32 8.50
NO. 31 8.30
NO. 33 8.67
NO. 30 8.75
NO. 29 9.77
NO. 28 8.33
+NO. 27a 11.53
NO. 27b 10.80
(+IMMERSED 4 WEEKS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 40.—*Absorption of Waterproofed Mortars.*

Age 13 weeks—1 part Portland cement to 8 parts No. 1 sand.

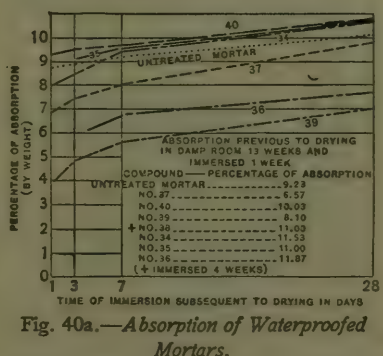
PERCENTAGE OF ABSORPTION (BY WEIGHT)
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 13 WEEKS AND IMMERSED 1 WEEK
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 9.23
NO. 37 6.57
NO. 40 10.03
NO. 39 8.10
+NO. 38 11.03
NO. 34 11.53
NO. 35 11.00
NO. 36 11.87
(+ IMMERSED 4 WEEKS)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 40a.—*Absorption of Waterproofed Mortars.*

Age 13 weeks—1 part Portland cement to 8 parts No. 1 sand.

In almost every respect the results of the tests made at the 13-week period were the same as those made at the 4-week period. One exception seems to be Compound No. 39, which was consider-

ably more effective at the 13-week period than at the 4-week period.

At the 26-week period most of the mortars containing compounds have practically the same absorption as the untreated

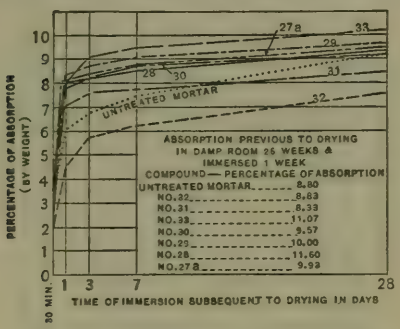

Fig. 41.—*Absorption of Waterproofed Mortars.*

Age 26 weeks—1 part Portland cement to 8 parts No. 1 sand.

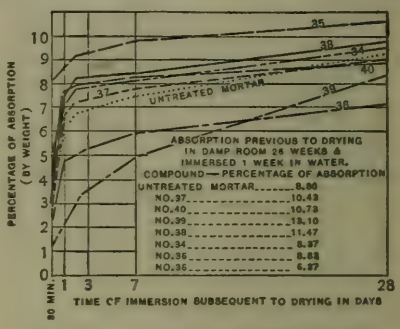

Fig. 41a.—*Absorption of Waterproofed Mortars.*

Age 26 weeks—1 part Portland cement to 8 parts No. 1 sand.

mortar but there are several exceptions. Compound No. 36 had decreased the absorption somewhat from the preceding age as has also Compound No. 32.

The absorption has decreased with the age of the mortar.

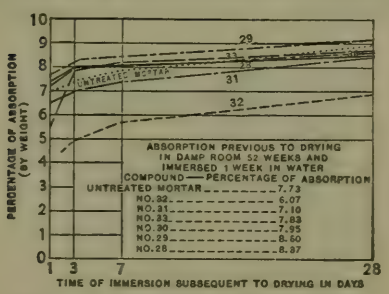
PERCENTAGE OF ABSORPTION (BY WEIGHT)
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS
UNTREATED MORTAR
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 52 WEEKS AND IMMERSED 1 WEEK IN WATER
COMPOUND — PERCENTAGE OF ABSORPTION
UNTREATED MORTAR 7.73
NO.32 6.07
NO.31 7.10
NO.33 7.83
NO.30 7.95
NO.29 8.50
NO.28 8.87

Fig. 42.—*Absorption of Waterproofed Mortars.*

Age 52 weeks—1 part Portland cement to 8 parts No. 1 sand.

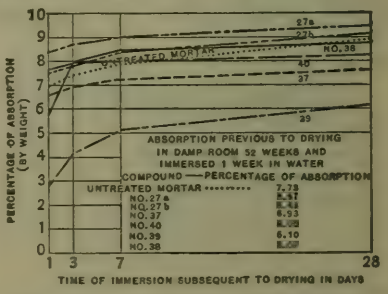

Fig. 42a.—*Absorption of Waterproofed Mortars.*

Age 52 weeks—1 part Portland cement to 8 parts No. 1 sand.

The effectiveness of only two of the compounds was evident at the 52-week period, all other mortars containing compounds having approximately the same absorption as the untreated mortar.

Comparing with Tables 20 and 21, it is of interest to note what a very little difference there was in the absorption of the lean and

rich mortars. While there was a small decrease, it is very small compared with the total absorption and the difference in the cement content.

Considering all of the absorption tests, it is evident that some of the compounds are slightly effective in reducing the absorption

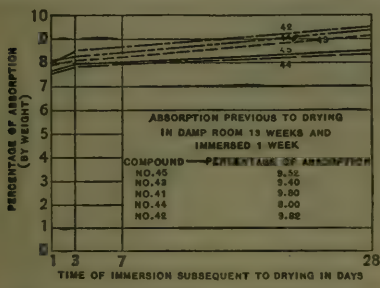
PERCENTAGE OF ABSORPTION (BY WEIGHT)
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 13 WEEKS AND IMMERSED 1 WEEK
COMPOUND — PERCENTAGE OF ABSORPTION
NO. 45 9.52
NO. 43 9.40
NO. 41 9.80
NO. 44 9.00
NO. 42 9.82
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 43.—*Absorption of Mortars Containing Inert Fillers.*

Age 13 weeks—1 part Portland cement to 4 parts No. 1 sand.

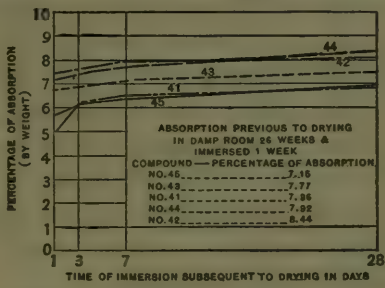
PERCENTAGE OF ABSORPTION (BY WEIGHT)
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 26 WEEKS & IMMERSED 1 WEEK
COMPOUND — PERCENTAGE OF ABSORPTION
NO. 45 7.15
NO. 43 7.77
NO. 41 7.96
NO. 44 7.92
NO. 42 8.44
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 44.—*Absorption of Mortars Containing Inert Fillers*

Age 26 weeks—1 part Portland cement to 4 parts No. 1 sand.

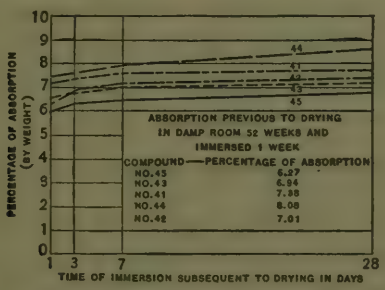
PERCENTAGE OF ABSORPTION (BY WEIGHT)
ABSORPTION PREVIOUS TO DRYING IN DAMP ROOM 52 WEEKS AND IMMERSED 1 WEEK
COMPOUND — PERCENTAGE OF ABSORPTION
NO. 45 6.27
NO. 43 6.94
NO. 41 7.38
NO. 44 8.08
NO. 42 7.01
TIME OF IMMERSION SUBSEQUENT TO DRYING IN DAYS

Fig. 45.—*Absorption of Mortars Containing Inert Fillers.*

Age 52 weeks—1 part Portland cement to 4 parts No. 1 sand.

after drying, even in the leaner mixtures and that hydrated lime is valueless, but on the other hand it is questionable if the slight reduction obtained is sufficient to warrant their use, and of course it is not practical to apply heat in actual construction.

Table 23 (Figs. 43, 44, 45).—The addition of inert materials seems to have little effect on absorption.

Table 24 (Figs. 46 to 51a).—In the 1–4 proportion mortar the addition of the compounds has in many cases slightly reduced the compressive strength.

The tensile strength was not perceptibly affected at the early ages and only slightly at 26 and 52 weeks by the addition of the compounds to the 1–4 proportion mortars.

The compressive strength has been slightly increased or practically unaffected in almost every case by the addition of the compounds to the 1–6 mortar, which might be expected in the case of the compounds acting as fillers and helping to increase the density of the mass. In fact, the mortar containing the 10 per cent of hydrated lime developed the greatest strength in compression.

The tensile strength has been practically unaffected by the addition of the compounds to the 1–6 proportion mortars.

In the 1–8 mixture at the early ages the treated mortars are slightly stronger in compression, but after 13 weeks the untreated mortar is the stronger.

The tensile strength in the 1–8 mixture has not been reduced by the addition of the compounds but in most cases has been slightly increased.

Table 25 (Figs. 52 and 53).—The compressive strength is increased by the addition of all but one of the inert fillers. The tensile strength has been slightly increased at early ages but is less than the untreated mortar at 52 weeks.

3. VALUE OF COATINGS AS DAMP-PROOFING MEDIUMS

Test pieces were 2 inches thick and 7½ inches in diameter. The mortar of which they were made was composed of 1 part of typical Portland cement to 4 parts of Meramec River sand retained on a No. 20 sieve.

In each case the coating was applied to one flat surface and entirely around the edge.

Compounds Nos. 1 and 3.—These compounds are manufactured by one firm and are used together. Compound No. 3 was first applied as a paint with an ordinary 3-inch flat brush, well brushed into the surface and permitted to dry for 24 hours, when Compound No. 1 was applied with the same style of brush.

All three test pieces failed in one-half inch of water. After removing from the water the coating was found to be soft and sticky.

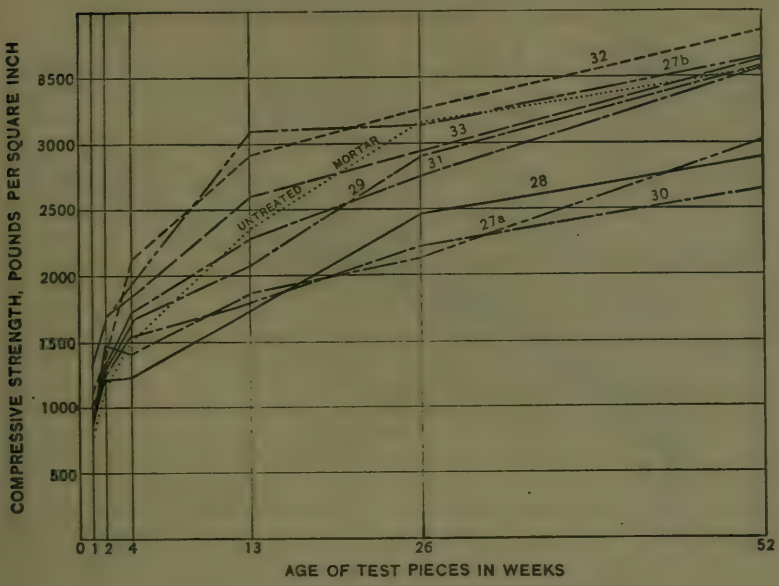

Fig. 46.—*Compressive Strength of Waterproofed Mortars.*

One part Portland cement to 4 parts No. 1 sand.

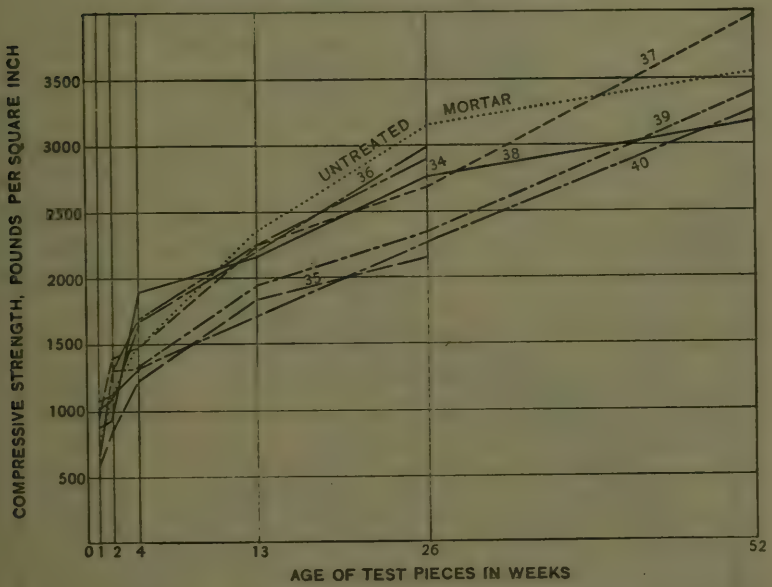

Fig. 46a.—*Compressive Strength of Waterproofed Mortars.*

One part Portland cement to 4 parts No. 1 sand.

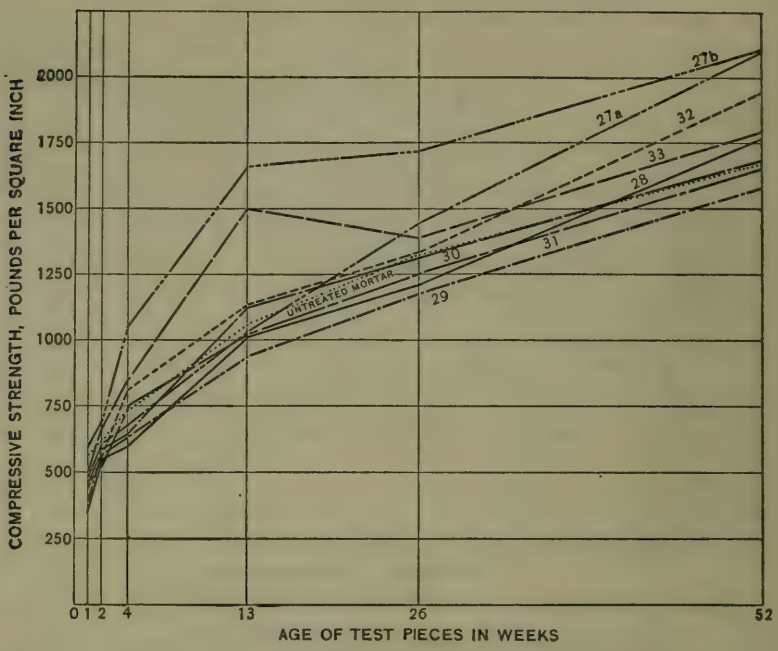

Fig. 47.—*Compressive Strength of Waterproofed Mortars.*

One part Portland cement to 6 parts No. 1 sand.

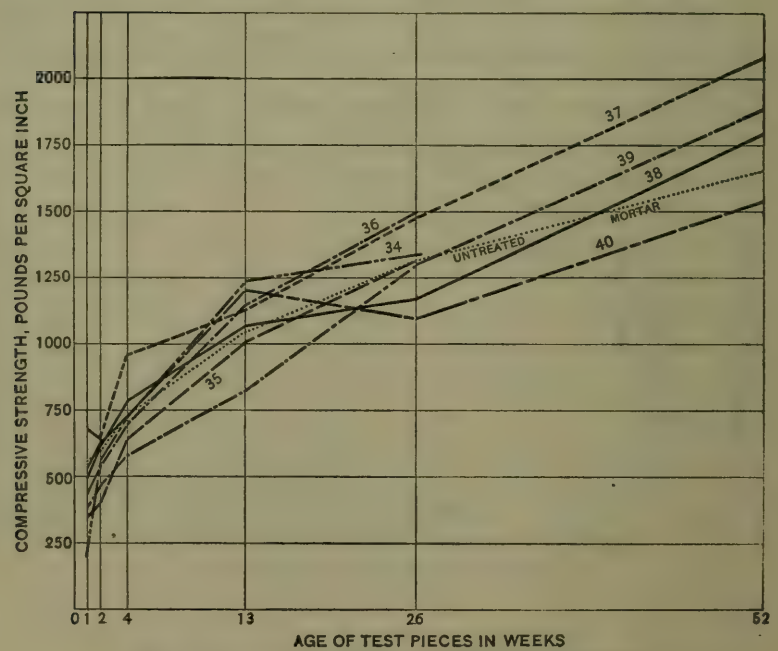

Fig 47a.—*Compressive Strength of Waterproofed Mortars.*

One part Portland cement to 6 parts No. 1 sand.

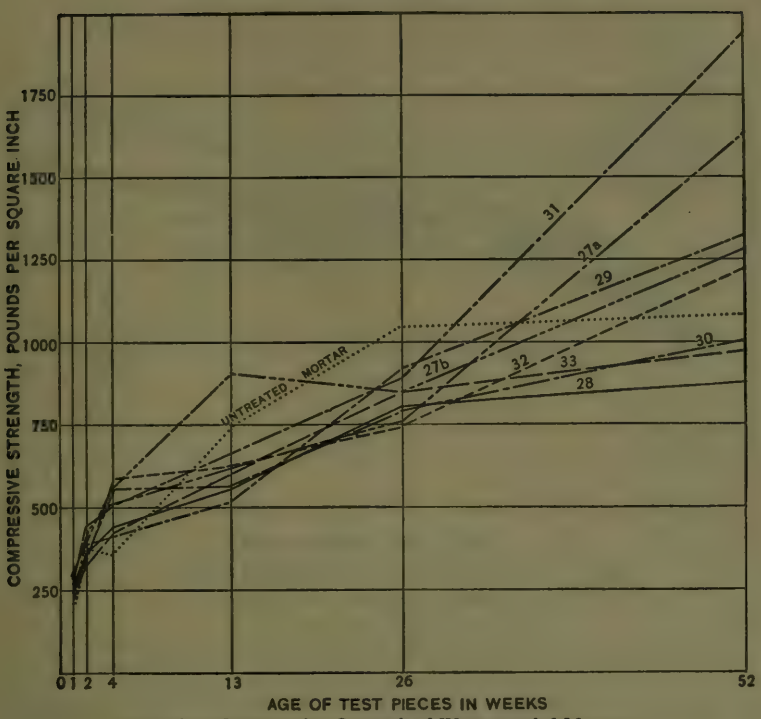

Fig. 48.—*Compressive Strength of Waterproofed Mortars.*

One part Portland cement to 8 parts No. 1 sand.

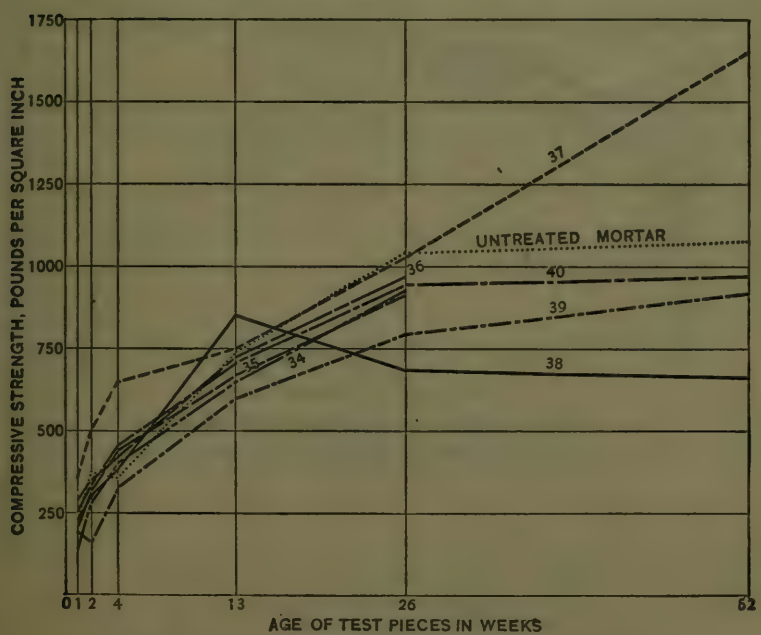

Fig. 48a.—*Compressive Strength of Waterproofed Mortars.*

One part Portland cement to 8 parts No. 1 sand.

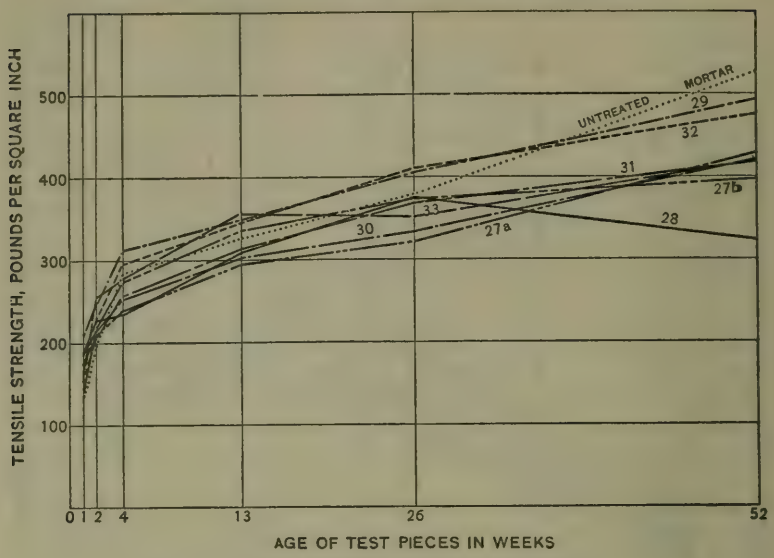

Fig. 49.—*Tensile Strength of Waterproofed Mortars.*

One part Portland cement to 4 parts No. 1 sand.

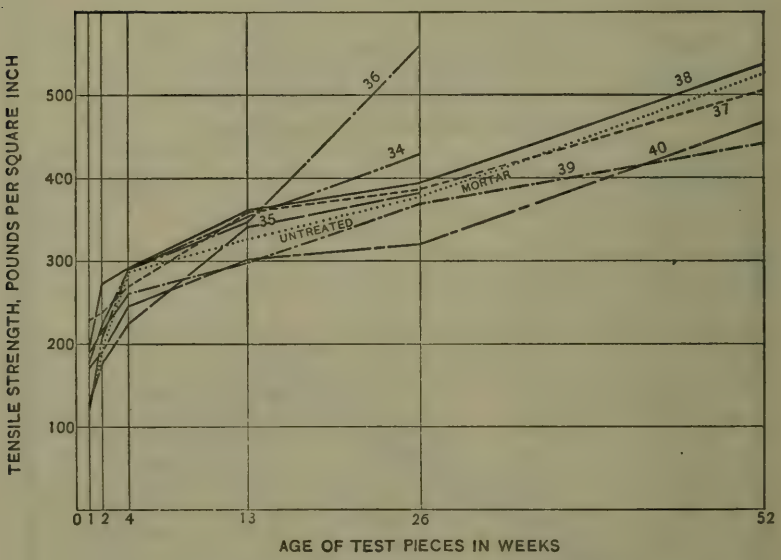

Fig. 49a.—*Tensile Strength of Waterproofed Mortars.*

One part Portland cement to 4 parts No. 1 sand.

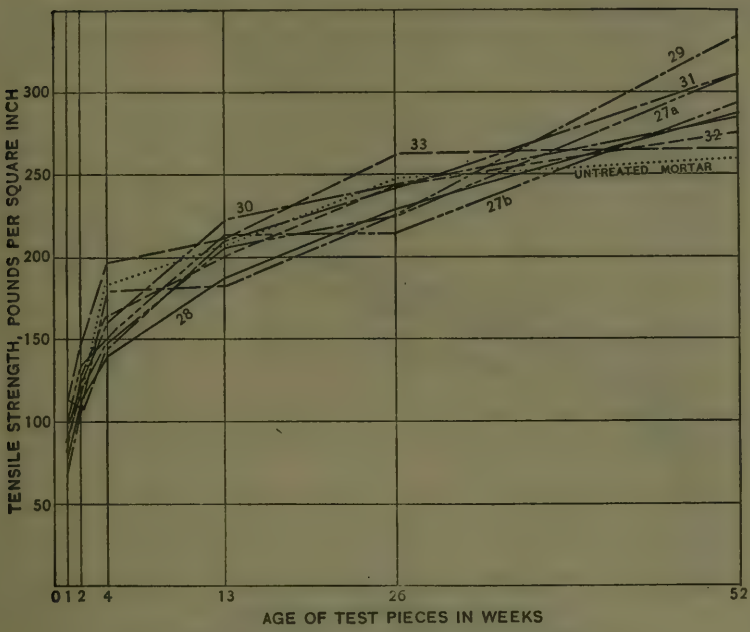

Fig. 50.—*Tensile Strength of Waterproofed Mortars.*

One part Portland cement to 6 parts No. 1 sand.

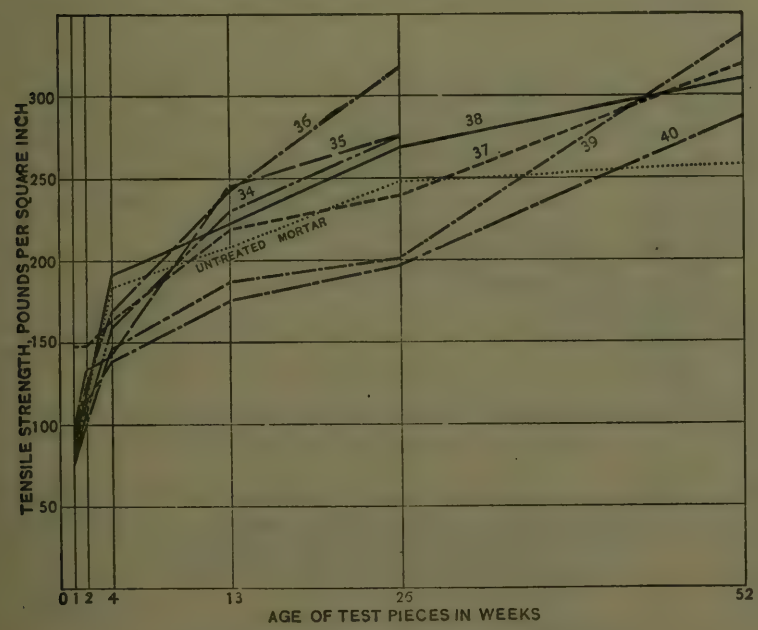

Fig. 50a.—*Tensile Strength of Waterproofed Mortars.*

One part Portland cement to 6 parts No. 1 sand.

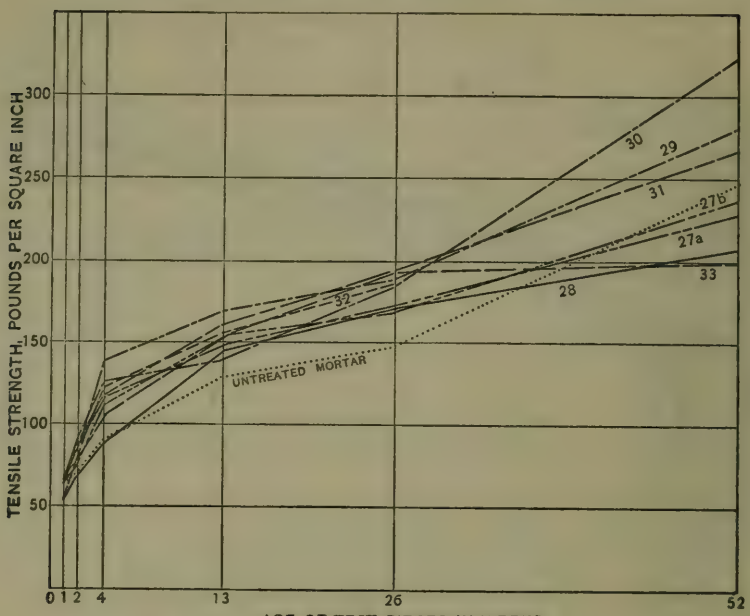

Fig. 51.—*Tensile Strength of Waterproofed Mortars.*

One part Portland cement to 8 parts No. 1 sand.

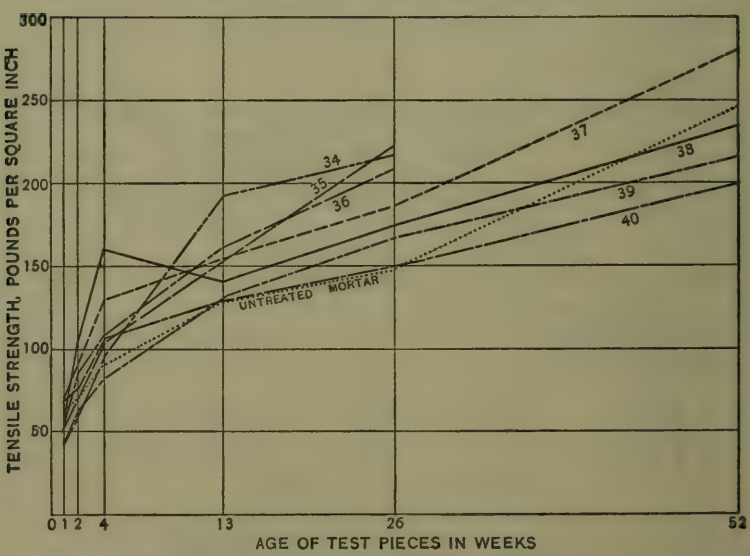

Fig. 51a—*Tensile Strength of Waterproofed Mortars.*

One part Portland cement to 8 parts No. 1 sand.

Compound No. 2.—Two coats of this compound were applied with a 3-inch flat brush, 24 hours intervening between coats.

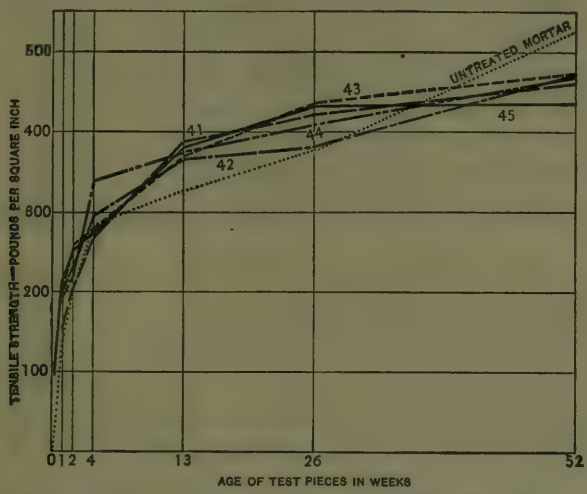

Fig. 52.—*Tensile Strength of Mortars Containing Inert Fillers.*
One part Portland cement to 4 parts No. 1 sand.

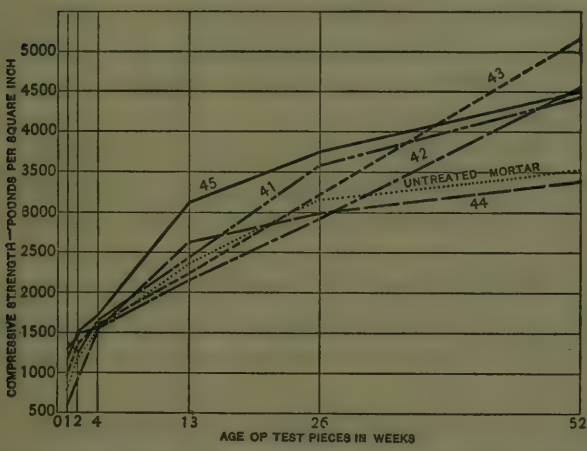

Fig. 53.—*Compressive Strength of Mortars Containing Inert Fillers.*
One part Portland cement to 4 parts No. 1 sand.

All three test pieces failed in one-half inch of water. After removing from the water the coating was found to be very soft, so that it could be rubbed off with the fingers.

Compound No. 4.—This compound was mixed with benzine to a paint consistency and applied with a 3-inch flat brush in two coats, 24 hours intervening between coats.

All three test pieces failed in one-half inch of water.

There was no visible change in the condition of the coating.

Compound No. 5.—The material was applied with a 3-inch flat brush as received in two coats at 24-hour intervals.

All three test pieces failed in one-half inch of water.

After removing from the water the coating was found to be soft and sticky.

Compound No. 6.—Two coats of this material were applied with a 3-inch flat brush at 24-hour intervals.

All three test pieces failed in one-half inch of water.

As this material was of a thin consistency and was mostly absorbed into the mortar, no change was visible, excepting the surface of the water near the test piece was observed to be oily at times.

Compound No. 7.—While this material was tested in the same manner as the others, it is hardly a fair test, considering the fact that the manufacturer recommends it for use only between the plaster coat and wall surface, where it will not be directly exposed to moisture. However, two coats were applied at 24-hour intervals in the usual manner.

All three test pieces failed in one-half inch of water.

Compound No. 8.—The remarks under Compound No. 7 also apply to this compound. Two coats were applied at 24-hour intervals.

All three test pieces failed in one-half inch of water.

Compound No. 9.—This compound was in a solid state and had to be melted to be applied. One coat only was applied with a flat brush.

Only one test piece failed in one-half inch of water.

The coating appeared in perfect condition when removed from the water and the failure was probably due to imperfect covering at the time coating was applied.

Compound No. 10.—The same remarks made under Compound No. 7 also apply to this compound. Two coats were applied, 24 hours intervening between coats.

All three test pieces failed in one-half inch of water.

Compound No. 11.—The material had settled in the container, and it was remixed only with considerable difficulty. Two coats were applied, 24 hours intervening between coats.

All three test pieces failed in one-half inch of water.

The coating was soft and sticky after removal from the water.

Compound No. 12.—Two coats of this compound were applied at 48-hour intervals.

All three test pieces failed in one-half inch of water.

The coating was soft and sticky after removal from the water.

Compound No. 13.—Two coats were applied at 24-hour intervals.

All three test pieces failed in one-half inch of water.

Compound No. 14.—Two coats were applied at 24-hour intervals.

All three test pieces failed in one-half inch of water.

The coating was soft and sticky after removal from the water.

Compound No. 15.—This compound is about of the consistency of kerosene oil, and was applied to the surface in two coats at 24-hour intervals. The mortar absorbed the compound very rapidly, and before placing in the water it was observed that the compound had penetrated to the opposite surface entirely through the 2-inch thickness.

All three test pieces failed in one-half inch of water.

Compound No. 16.—The compound as received from the manufacturer is of the consistency of milk, but before applying was thinned down according to directions, with two parts of water. Two coats were applied to the surface with a 3-inch flat brush at 24-hour intervals.

All three test pieces failed in one-half inch of water.

Compound No. 17.—Two coats were applied at 24-hour intervals.

Two test pieces failed in one-half inch of water, but the third test piece withstood this exposure for three months, when it was placed in 1 inch of water, where it failed.

Compound No. 18.—Two coats were applied at 24-hour intervals. One test piece failed in one-half inch of water, and after three months the other two test pieces were placed in 1 inch of water, where they failed.

Compound No. 19.—Two coats were applied at 24-hour intervals. Two test pieces failed in one-half inch of water, but the third test piece did not fail, although exposed for three months. It was then placed in 1 inch of water, where it failed.

Compound No. 20.—This compound was applied to the surface in two coats at 24-hour intervals.

All three test pieces failed in one-half inch of water.

Compound No. 21.—The compound was received in solid form and was dissolved in hot water, as directed by the manufacturer. It was applied to the surface in two coats, at 24-hour intervals.

All three test pieces failed in one-half inch of water.

Compound No. 22.—Two coats were applied at 24-hour intervals. One test piece failed in one-half inch of water, and after three months the other two were placed in 1 inch of water, where they failed.

Compound No. 24.—This compound was mixed with water in the proportion of 1 part by volume of water to 2 parts of compound. It was thoroughly stirred until the mixture was smooth and free from lumps, when it was thinned down with additional water to the consistency of thick cream, after which it was further thinned down and applied. Two coats were applied at 24-hour intervals.

All three test pieces failed in one-half inch of water. The coating was in very bad condition when the test pieces were removed from the water. The odor was very bad and parts of the coating had molded, breeding maggots.

Compound No. 25.—Water was added to this compound, complying with the directions of the manufacturers, until the mixture was about the consistency of paste. It was applied to the mortar with a stiff brush in two coats at 24-hour intervals. The test pieces were kept in a damp atmosphere after applying coating.

All three test pieces remained sound in one-half inch of water for three months and in 1 inch of water for three months. The

coating could be rubbed off somewhat by the fingers but otherwise it appeared sound.

Compound No. 26.—Two coats of this compound were applied at 24-hour intervals.

All three test pieces failed in one-half inch of water.

XIII. SUMMARY

Portland cement mortar and concrete can be made practically water-tight or impermeable (as defined below) to any hydrostatic head up to 40 feet without the use of any of the so-called "integral" waterproofing materials; but in order to obtain such impermeable mortar or concrete considerable care should be exercised in selecting good materials as aggregate and proportioning them in such a manner as to obtain a dense mixture. The consistency of the mixture should be wet enough so that it can be puddled, the particles flowing into position without tamping. The mixture should be well spaded against the forms when placed, so as to avoid the formation of pockets on the surface.

The addition of so-called "integral" waterproofing compounds [12] will not compensate for lean mixtures, nor for poor materials, nor for poor workmanship in the fabrication of the concrete. Since in practice the inert integral compounds (acting simply as void filling material) are added in such small quantities, they have very little or no effect on the permeability of the concrete. If the same care be taken in making the concrete impermeable without the addition of waterproofing materials as is ordinarily taken when waterproofing materials are added, an impermeable concrete can be obtained.

The terms "permeability," "absorption," and "damp proof" should not be confused. A mortar or concrete is impermeable (not necessarily damp proof), as defined and used throughout this report, when it does not permit the passage or flow of water through its pores or voids. The absorption of a mortar or concrete is the property of drawing in or engrossing water into its pores or voids by capillary action or otherwise. If the pores or voids between

[12] Since the completion of the investigation reported above subsequent tests of similar materials have urther shown the ineffectiveness of such materials.

the grains or particles or in the individual grains are sufficiently large and connected from surface to surface of the wall, the concrete will be permeable to water. If the pores or voids are very minute, but connect one with another, theoretically they may act as capillary tubes, absorbing or drawing in and filling themselves with water; but the capillary forces will tend to hold the water in the pores and will prevent the passage or flow of water, even though one surface of the wall may be exposed to a considerable hydrostatic pressure. For all practical purposes a wall under such conditions would be considered perfectly water-tight and impermeable, although it may be highly absorptive. If these minute pores do act as capillary tubes and are never minute enough to prevent capillary action, the moisture either as water or water vapor would in time penetrate entirely through and fill a concrete wall, no matter what the thickness or composition. In such a case the capillary forces would not permit an actual flow of water, but these forces may carry moisture, entirely filling the wall, and, unless evaporation is retarded, the opposite face of the wall would appear dry. In such a case the concrete would be considered impermeable, but not damp proof.

The damp-proofing tests as conducted would indicate that Portland cement mortars can be made not only impermeable but damp proof as well, as defined above, without the use of any damp-proofing [13] or waterproofing compound. However, these tests should be interpreted with caution, as the evaporation may have been sufficient to care for the slight amount of moisture coming through the test pieces without indicating on the filter paper. Thus it can not be stated that if a material were used which was damp proof according to this test, if used as a basement wall, one surface being constantly exposed to moisture and the other surface in an inclosed room where there would be little or no circulation of air, that the interior surface would not appear damp and the atmosphere become saturated with moisture. The tests of coating materials as damp-proofing mediums can be considered as only preliminary, but the results, considered along with the chemical discussion, throw some light on their comparative merits. The

[13] See note on p. 83.

mortar used in these tests was, perhaps, too coarse and too absorptive for a fair test. The purpose of the rough surface was to test the flowing qualities of the coating, and it would seem that many of the failures may be due to the poor or imperfect spreading and adhesive quality. Several of the compounds deteriorated and proved their unfitness for the purpose intended.

Well graded sands containing considerable graded fine material are preferable for making impermeable concrete, but if such is not to be had, fine material in the form of hydrated lime, finely ground clay, or an additional quantity of cement will be found of value.

Where Portland cement mortar is used as a plaster coat, if sufficient cement be used and the sand contains sufficient fine material (or a fine material be added) and the mortar be placed without joints and well troweled (care being taken not to overtrowel, which may cause crazing), the coating will be effective as an impermeable medium without the use of any waterproofing compound.

As a precaution, under certain conditions, it is undoubtedly desirable to use bituminous or similar coatings, even on new work, as protection where cracks may occur due to settling of foundation or expansion and contraction caused by temperature changes. In large or exposed work it is practically impossible to prevent some cracks, but where cracks can be prevented no coating whatever is required to make the structure impermeable.

The permeability of Portland cement mortars and concretes rapidly decreases with age.

None of the integral compounds tested materially reduced the absorption of the mortars before they were dried by heating at 212° F. Thus they would have little or no practical value. But some of the so-called integral waterproofing compounds did decrease the absorption obtained after drying the mortars at 212° F., and the rate of absorption was much slower in these cases. The addition of hydrated lime and clays seemed to have little or no effect on the absorption.

The addition of any of the compounds tested to a mortar in the quantities as used in these tests does not seriously affect the com-

pressive or tensile strength. The addition of the inert void fillers to mortars, as used in these tests, up to 20 per cent of the volume of cement increases the compressive strength.

WASHINGTON, D. C., August 24, 1911.

Table of equivalents

Pounds per square inch	Kilograms per square centimeter	Cubic inches	Cubic millimeters	Avoirdupois ounces	Grams
20	1.41	0.000061 =	1	0.03527 =	1
40	2.81	0.000122 =	2	0.07055 =	2
60	4.22	0.000183 =	3	0.10582 =	3
80	5.62	0.000244 =	4	0.14110 =	4
		0.000305 =	5	0.17637 =	5
		0.000366 =	6	0.21164 =	6
		0.000427 =	7	0.24692 =	7
		0.000488 =	8	0.28219 =	8
		0.000549 =	9	0.31747 =	9

TABLE 1.—Permeability of Mortars

Thickness of Test Piece, 1 Inch. Consistency, Quakin

[The values are averages of 3 test pieces, except that individual values are given at end of test.]

Proportion, by volume, of Portland cement to Meramec River sand	Age in weeks when tested	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. 1-minute readings taken at end of periods given. Average								
			10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours [First three are individual values]
1–2	4	1, 2, 3	0	0	0	0	0	0	0	0	0, 0, 0, 0
	8	4, 5, 6	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	7, 8, 9	0	0	0	0	0	0	0	0	0, 0, 0, 0
1–4	4	10, 11, 12	0	0	0	0	0	10	10	10	10, 10, 10, 10
	8	13, 14, 15	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	16, 17, 18	0	0	0	0	0	0	0	0	0, 0, —, 0
1–6	4	19, 20, 21	—	395	579	474	421	395	369	342	—, —, —, —
	8	22, 23, 24	0	0	0	0	5	8	8	8	8, 8, 8, 8
	26	25, 26, 27	5	21	29	21	27	19	19	19	8, 24, 24, 19
1–8	4	28, 29, 30	1820	1690	1550	1500	1510	1550	1490	1490	1820, 1180, 1340, 1450
	8	[13]31, 32, 33	1190	985	985	985	995	985	985	905	1180, 630, 905
	26	34, 35, 36	30	120	130	130	110	100	110	80	50, 100, 80, 80

Thickness of Test Piece, 2 Inches. Consistency, Quaking

1–2	4	37, 38, 39	0	0	0	0	0	0	0	—	—, —, —, —
	8	40, 41,[14]42	0	0	0	0	0	0	0	0	0, 0, —, 0
	26	43, 44, 45	0	0	0	0	0	0	0	0	0, 0, 0, 0
1–4	4	46, 47, 48	0	0	0	0	0	10	10	10	10, 10, 10, 10
	8	49, 50, 51	0	0	0	0	0	0	0	0	—, —, —, —
	26	52, 53, 54	0	0	0	0	0	0	0	0	[15] 0, [15] 0, 0, 0
1–6	4	55, 56, 57	270	270	290	290	270	240	240	240	280, 160, 200, 210
	8	58, 59, 60	0	0	0	20	20	20	20	20	20, 20, 20, 20
	26	61, 62, 63	0	0	0	8	8	8	16	8	8, 8, 8, 8
1–8	4	64, 65, 66	3090	3030	3550	3240	3240	3420	3320	3240	4190, 3400, 2130, 3240
	8	67, 68, 69	1580	1580	1500	1390	1400	1320	1320	1320	—, —, 1580, 1580
	26	70, 71, 72	0	180	160	130	110	90	90	90	60, 110, 90, 90

Thickness of Test Piece, 3 Inches. Consistency, Quaking

1–2	4	73, 74, 75	0	0	0	0	—	—	—	—	—, —, —, —
	8	76, 77, 78	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	79, 80, 81	0	0	0	0	0	0	0	0	0, 0, 0, 0
1–4	4	82, 83, 84	0	0	0	0	0	0	0	0	10, 0, 0, 3
	8	85, 86, 87	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	[16] 88, 89, 90	0	0	0	0	0	0	0	0	—, —, 0, —
1–6	4	91, 92, 93	290	290	290	210	210	210	210	170	80, 160, 200, 150
	8	94, 95, 96	30	40	40	50	50	50	50	50	40, 40, 80, 50
	26	97, 98, 99	0	0	0	0	0	0	0	5	8, 0, 8, 5
1–8	4	100, 101, 102	15100	12800	11300	10500	9610	8950	8150	7490	9870, 5920, 4340, 6710
	8	103, 104, 105	2310	2180	1920	1710	1500	1370	1390	1260	2370, 240, 1180, 1260
	26	106, 107, 108	1420	1240	970	830	770	660	640	430	710, 550, 150, 470

[13] No. 31 broken while clamping.
[14] No. 42 broken while clamping.
[15] Test continued for 144 hours. No. 52, 24 hours surface moist; 48, 72, 96, 120, and 144 hours moist. No 53, 24 hours surface moist; 48, 72, and 96 hours moist; 120 and 144 hours dry.
[16] Two specimens remained impermeable throughout test; third specimen showed a flow varying from 5130 to 3630 tenths of cubic millimeters.

TABLE 2.—Permeability of Mortars

Thickness of Test Piece, 2 Inches. Consistency, Damp

Proportions by volume of Portland cement to Meramec River sand	Age in weeks when tested	Test piece No.	Cubic centimeters of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at end of following periods								
			10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
1–2	1	109	17.20	12.20	8.45	2.53	1.82	1.66	1.26	1.58	1.58
	1	110	22.90	8.10	6.00	2.13	1.66	1.34	0.99	1.22	1.18
	1	111	78.90	55.30	31.60	27.60	20.80	16.00	13.90	.....	.....
Average	.....	.....	39.70	25.20	15.35	10.75	8.09	6.33	5.38	1.40	1.38
1–2	2	112	32.40	22.10	19.70	12.70	11.10	8.14	7.98	7.11	6.71
	2	113	16.70	11.60	10.40	7.42	6.71	5.53	5.61	5.21	4.90
	2	114	20.20	5.92	5.13	3.24	3.08	2.92	2.13	1.97	2.05
Average	.....	.....	23.10	13.21	11.78	7.79	6.96	5.53	5.24	4.76	4.55
1–2	4	115	8.69	6.87	4.98	4.30	3.24	2.45	1.82	1.42	1.42
	4	116	7.11	5.92	4.74	4.26	3.32	2.84	2.13	1.66	1.58
	4	[18] 117	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	7.90	6.40	4.86	4.28	3.28	2.65	1.98	1.54	1.50
1–4	1	118	29.80	20.10	15.80	12.60	6.71	5.21	3.87	3.75	3.24
	1	119	23.70	14.60	10.70	8.17	3.87	2.84	2.05	2.05	1.74
	1	120	94.80	92.60	82.10	71.10	62.00	55.80	45.10	44.20	39.50
Average	.....	.....	49.40	42.40	36.20	30.62	24.19	21.58	17.01	16.67	14.83
1–4	2	121	19.20	14.10	11.10	7.89	5.61	3.95	3.79	3.84	3.24
	2	122	8.77	6.48	5.13	2.53	2.53	2.25	1.82	1.90	2.13
	2	123	105.00	98.70	78.90	57.70	41.10	32.40	28.60	25.30	18.20
Average	.....	.....	44.32	39.76	31.71	22.71	16.41	12.87	11.40	10.23	7.85
1–4	4	124	11.60	7.89	6.56	3.24	3.24	2.37	1.82	1.93	2.25
	4	125	19.10	16.00	12.10	4.98	4.42	4.11	3.24	3.16	3.16
	4	126	61.60	37.10	23.70	9.64	7.74	7.11	5.84	5.29	5.05
Average	.....	.....	30.80	20.33	14.12	5.95	5.13	4.53	3.63	3.46	3.49
1–6	1	127	40.30	28.00	25.70	13.60	13.50	11.80	9.95	8.60	7.89
	1	128	117.60	109.40	102.70	86.90	77.50	71.10	59.40	57.60	54.50
	1	129	104.30	63.00	53.30	44.20	32.40	19.70	17.80	16.00	15.00
Average	.....	.....	87.40	66.80	60.60	48.20	41.10	34.20	29.05	27.40	25.80
1–6	2	130	36.70	30.40	23.90	15.00	10.10	8.29	7.74	6.32	4.90
	2	131	55.70	51.30	45.00	26.10	23.70	19.50	19.40	18.00	15.80
	2	[18] 132	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	46.20	40.90	34.50	20.60	16.90	13.90	13.57	12.16	10.35
1–6	4	133	13.00	11.10	8.45	6.40	5.05	4.38	4.30	4.26	3.55
	4	134	31.00	29.50	22.20	16.70	14.20	12.10	10.40	9.87	8.69
	4	[18] 135	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....	.....	22.00	20.30	15.33	11.55	9.63	8.24	7.35	7.07	6.12

[18] Not tested.

TABLE 3.—Permeability of Mortars

Consistency, Quaking

Proportions by volume of Portland cement to torpedo sand	Thickness of test piece in inches	Age in weeks when tested	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at end of following periods								
				10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
1–2	2	4	190	0	0	0	0	0	0	0	0	0
	2	4	191	79	110	102	46	39	24	32	20	20
	2	4	192	631	671	553	197	126	72	72	72	59
Average				237	260	219	81	55	32	35	31	26
1–2	2	8	193	0	0	0	0	0	0	0	0	0
	2	8	194	0	0	0	0	0	0	0	0	0
	2	8	195	0	0	0	0	0	0	0	0	0
Average				0	0	0	0	0	0	0	0	0
1–2	2	26	196	0	0	0	0	0	0	0	0	[19] 0
	2	26	197	0	0	0	0	0	0	0	0	[19] 0
	2	26	198	0	0	0	0	0	0	0	0	[19] 0
Average				0	0	0	0	0	0	0	0	0
1–2	2	4	199	0	0	0	0	0	0	0	0	0
	3	4	200	0	0	0	0	6	5	4	4	4
	3	4	201	0	0	0	0	6	6	3	3	3
Average				0	0	0	0	4	4	2	2	2
1–2	3	8	202	9880	8290	7900	6710	5520	3950	3550	3160	3160
	3	8	203	18950	9480	7110	3950	2370	1580	1420	1420	1180
	3	8	204	47000	35500	34800	26900	19000	17400	16600	15800	15000
Average				23280	17760	15600	12520	8970	7640	7190	6790	6450
1–2	3	26	205	0	0	0	0	0	0	0	0	[19] 0
	3	26	206	0	0	0	0	0	0	0	0	[19] 0
	3	26	207	0	0	0	0	0	0	0	0	[19] 0
Average				0	0	0	0	0	0	0	0	0

[19] Test continued for 23 hours; all surfaces dry, no flow.

TABLE 4.—Permeability of Limestone Concrete

Thickness of Test Piece, [a]2 and [b]3 Inches. Consistency, Quaking

["Proportions" of cement, sand, and stone (by volume).]

Proportion of material	Age in weeks when tested	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure, one-minute readings taken at end of periods given. [m=moist]								
			Average								7 hours [First three are individual values]
			10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	
[a]1–2–4	4	136,137,138	70	60	70	60	50	50	50	50	120, 0, 20, 50
	8	139,140,141	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	142,143,144	0	0	0	0	0	0	0	0	0, 0, 0, 0
[a]1–3–6	4	145,146,147	60	60	90	.....	90	.....	90	.....	60, —,120, 90
	8	148,149,150	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	151,152,153	0	0	0	0	0	3	[20] 3	[21] 4	—, —, —, —
[a]1–4–8	4	154,155,156	240	200	200	.....	490	.....	330	.....	320, 80,120,170
	8	157,158,159	110	160	160	160	160	160	160	160	160, 160,160,160
	26	160,161,162	4100	3650	3430	3300	3100	3200	3100	[22] 2990	—, —, —, —
[b]1–2–4	4	163,164,165	0	0	0	0	0	0	0	0	m, m, m, m
	8	166,167,168	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	169,170,171	0	0	0	0	0	0	0	0	0, 0, 0, 0
[b]1–3–6	4	172,173,174	7	7	7	20	20	20	20	20	20, 20, 20 ,20
	8	175,176,177	0	0	0	0	0	0	0	0	0, 0, 0, 0
	26	178,179,180	0	0	0	0	0	0	0	0	0, 0, 0, 0
[b]1–4–8	4	181,182,183	740	820	920	990	1080	1240	970	840	1180,1180, 80,810
	8	184,185,186	390	260	260	260	130	130	130	130	0, 400, 0,130
	26	187,188,189	1240	1370	1150	1010	1010	900	930	950	1580,1260, 20,950

[20] Separate values m, o, 8. [21] Separate values —, o, 8. [22] Separate values 16, 8850, 100

TABLE 5.—Retest of Permeability Test Pieces

Consistency, Quaking

Thickness of test piece in inches	Test piece No.	Proportion of cement to sand or sand and stone	Age in weeks when re-tested	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrastatic pressure. One-minute readings taken at end of following periods								
				10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
1	4	1–2	12	0	0	0	0	0	0	0	0	0
	10	1–4	12	0	0	0	0	0	0	0	0	0
	13	1–4	12	0	0	0	0	0	0	0	0	0
	28	1–8	8	950	790	630	550	790	790	950	950	950
2	37	1–2	8	0	0	0	0	0	0	0	0	0
	40	1–2	12	0	0	0	0	0	0	0	0	0
	46	1–4	8	0	0	0	0	0	0	0	0	.....
	49	1–4	12	0	0	0	0	0	0	0	0	0
	55	1–6	8	0	0	0	0	0	0	0	0	0
	58	1–6	12	40	40	40	30	30	20	20	20	20
	136	1–2–4	8	0	0	0	0	0	0	0	0	0
	145	1–3–6	8	0	0	0	0	0	0	0	0	0
	154	1–4–8	8	0	40	40	40	40	40	40	40	40
3	82	1–4	8	0	0	0	0	0	0	0	0	0
	85	1–4	12	0	0	0	0	0	0	0	0	0
	91	1–6	8	0	0	0	0	20	20	20	20	.....
	100	1–8	8	4340	4340	4110	.....	3550	3320	3320	3160	3160
	181	1–4–8	8	240	240	240	240	240	240	160	160	160

TABLE 6.—Permeability of Concrete

Quaking consistency. Age 13 weeks. Thickness 6, inches

Proportions (by volume) One part typical Portland cement to given parts of sand and stone	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface. One-minute readings taken at the end of the periods given. [m=moist]										Remarks
	Subjected to 1.4 kilograms hydrostatic pressure						2.8 kilogram pressure		4.2 kilogram pressure		
	10 minutes	30 minutes	1 hour	2 hours	Period in hours	Flow	Period in hours	Flow	Period in hours	Flow	
No. 4 sand to No. 6 stone											
0–6	0	0	m	m	22	m	24	m	.....	.....	Moist around edge only
½–5½	0	0	0	0	24	0	24	m	24	m	Moist in spots
1–5	0	0	0	0	8 24	0 m	24	3	.....	.....	Moist evenly
1½–4½	0	0	0	0	24	0	24	m	24	3	Leaked irregularly
2–4	0	0	m	m	48	m	24	6	.....	.....	Leaked evenly
3–3	0	0	3	6	22	16	.....	.....	.....	.....	Do.
0–9	114	102	65	.....	.....	.....	.....	.....	.....	.....	Leaked around edges
1–8	m	m	15	9	4 22	6 m	2	19	.....	.....	Leaked evenly
1½–7½	0	0	0	0	24	0	24	m	24	m	Moist evenly
2–7	m	m	12	12	3	6	22	19	.....	.....	Leaked evenly
3–6	241	247	278	247	.....	.....	.....	.....	.....	.....	Leaked in spots
4–5	142	136	108	108	.....	.....	.....	.....	.....	.....	Do.
No. 5 sand to No. 6 stone											
½–5½	0	0	0	0	24	0	24	0	24	0	Tested 5.6 kilograms pressure 24 hours remained dry
1–5	0	0	0	0	24	0	49	m	.....	.....	Moist in spots
2–4	0	0	0	0	24	0	24	m	72	m	Water drops hanging
3–3	0	0	0	m	3 4	m 1	.....	.....	.....	.....	Leaked 1 drop in 3 minutes
1–8	m	m	6	6	6 24	6 9	.....	.....	.....	.....	Leaked evenly
2–7	0	0	0	0	6 24	0 m	2	6	.....	.....	Do.
3–6	123	215	222	241	.....	.....	.....	.....	.....	.....	Do.
4–5	0	0	m	77	3	68	.....	.....	.....	.....	Do.

TABLE 7.—Permeability of Mortars

Quaking Consistency. Test Pieces 2 Inches Thick, Surfaces Trowelled.

Proportion by volume of cement to No. 1 sand	Age in weeks when tested	Pressure in Kg. per cm.[2]	Flow in cu. cm. per sq. cm. per minute		Proportion by volume of cement to No. 1 sand	Age in weeks when tested	Pressure in Kg. per cm.[2]	Flow in cu. cm. per sq. cm. per minute	
			Hours exposure	Flow [23]				Hours exposure	Flow [23]
1–1	1	5.6	24	0, 0, 0, 0		12	1.4	7	.10, .10, .20, .13
1–2	1	1.4	2	m, m, m, m		14	1.4	7	.1, m, m, .03
	2	1.4	3	m, m, m, m		16	1.4	24	.1, m, m, .03
	4	1.4	24	0, 0, 0, 0		18	1.4	24	m, m, m, m
	4	2.8	24	0, 0, 0, 0		20	1.4	24	0, 0, m, m
	4	4.2	24	0, 0, 0, 0	1–5	22	1.4	24	0, 0, 0, 0
	4	5.6	4	m, m, 0, m		22	2.8	24	0, 0, m, m
	13	5.6	6	0, 0, 0, 0		22	4.2	24	m, m, m, m
1–3	1	[24]5.6 and 1.4	3	1.2, .6, 1.8, 1.20		24	5.6	24	m, m, m, m
	2	1.4	3	.5, .4, .2, .37		26	5.6	24	m, m, m, m
	4	1.4	3	.1, .3, .2, .20		28	5.6	24	m, m, m, m
	6	1.4	3	0, m, m, m		30	5.6	24	0, m, m, m
1–4	1	1.4	4	1.4, 1.3, 1.1, 1.27		10	1.4	7	.1, m, m, .03
	2	1.4	2	.5, .4, .4, .43		12	1.4	5	.1, .1, m, .07
	4	1.4	2	.3, .2, .2, .23		14	1.4	24	m, m, m, m
	10	1.4	2	0, 0, 0, 0	1–6	16	1.4	2	m, m, m, m
	13	1.4	24	0, 0, 0, 0		18	2.8	24	m, m, m, m
	13	2.8	24	m, m, m, m		20	2.8	24	m, m, m, m
	17	2.8	24	m, m, m, m		22	5.6	24	0, 0, 0, 0
	19	2.8	24	0, 0, m, m		22	5.6	[25] 2	0, 0, m, m
	22	5.6	24	0, 0, m, m					
	24	5.6	[25] 2	0, 0, 0, 0					

[23] Shown by Test Pieces Nos. 1, 2, 3, and average, in the order indicated.
[24] This high pressure was applied for one hour by mistake.
[25] Weeks.

TABLE 8.—Absorption of Portland Cement Mortars

MERAMEC RIVER SAND NO. 1

[Results are averages of 3 test pieces for each set]

Proportion of cemen. to sand	Consistency	Per cent water used	Age of test pieces in weeks	Dry weight in grams	Percentage of absorption	
					Weight	Volume
1–2	Damp	8.67	1	239.5	12.76	23.3
			2	241.5	13.87	25.6
			4	251.5	10.54	20.2
			8	253.3	10.23	19.8
			26	248.3	10.50	19.9
1–2	Quaking	13.67	4	279.3	5.27	11.2
			8	267.8	8.26	16.9
			26	266.2	8.30	16.8
1–4	Damp	6.50	1	228.3	15.48	26.9
			2	221.0	17.87	30.1
			4	235.0	13.20	23.7
			8	243.3	11.11	20.6
			26	239.2	5.99	10.9
1–4	Quaking	13.00	4	248.7	8.66	16.4
			8	251.3	8.86	17.0
			26	250.0	9.95	18.0
1–6	Damp	6.00	1	230.0	15.95	29.5
			2	224.8	17.20	27.1
			4	227.5	15.60	27.2
			8	234.2	15.25	21.1
			26	230.7	11.96	17.9
1–6	Quaking	12.50	4	241.3	9.74	18.4
			8	250.0	9.67	23.9
			26	244.4	12.83	25.3
1–8	Damp	5.50	4	217.8	15.22	30.0
			8	225.2	17.47	19.5
			26	222.7	11.49	23.1
1–8	Quaking	12.00	4	234.5	12.94	24.3
			8	232.1	13.74	17.3
			26	233.5	9.72	

TABLE 9.—Absorption of Portland Cement Mortars

TORPEDO SAND NO. 2

[Results are averages of 3 test pieces for each set]

Proportion of cement to sand	Consistency	Per cent water used	Age of test pieces in weeks	Dry weight in grams	Percentage of absorption	
					Weight	Volume
1–2	Damp	6.20	4	271.5	8.61	17.8
			8	264.5	9.84	19.9
			26	262.1	9.51	19.0
1–2	Quaking	10.16	4	263.3	10.14	20.3
			8	273.1	7.91	16.5
			26	270.0	8.16	16.8
1–4	Damp	4.92	4	235.3	16.43	29.5
			8	235.3	15.05	27.0
			26	232.7	13.61	24.2
1–4	Quaking	9.70	4	246.0	11.87	22.9
			8	250.3	9.95	19.0
			26	254.8	9.42	18.3
1–6	Damp	4.75	4	235.8	14.25	25.6
			8	233.2	14.51	25.8
			26	232.9	13.40	23.8
1–6	Quaking	9.25	4	249.4	9.98	19.0
			8	249.8	9.79	18.7
			26	250.6	9.90	18.9
1–8	Damp	5.50	4	233.3	15.15	27.0
			8	230.0	14.64	25.7
			26	229.8	13.09	23.9
1–8	Quaking	8.00	4	249.8	9.16	17.5
			8	247.9	10.46	19.8
			26	248.3	11.28	21.4

TABLE 10.—Absorption of Portland Cement Mortars

SLAG SAND NO. 3

[Results are averages of 3 test pieces for each set]

Proportion of cement to sand	Consistency	Per cent water used	Age of test pieces in weeks	Dry weight in grams	Percentage of absorption	
					Weight	Volume
1–2	Damp	5.50	4	207.8	20.54	32.6
			8	214.6	20.54	33.6
			26	217.5	16.38	27.2
1–2	Quaking	13.8	4	236.8	12.17	22.0
			10	231.2	14.86	26.2
			26	233.3	10.99	19.9
1–4	Damp	8.00	4	201.9	20.45	31.5
			10	207.1	22.41	35.4
			26	204.4	20.10	31.3
1–4	Quaking	15.00	4	216.2	14.96	24.7
			10	217.3	15.41	25.6
			26	224.6	13.42	23.0
1–6	Damp	8.00	4	198.5	23.82	36.0
			10	199.6	24.21	36.9
			26	198.5	23.19	35.1
1–6	Quaking	15.00	4	200.7	18.64	28.5
			10	205.0	18.30	28.6
			26	204.7	17.41	27.2
1–8	Damp	9.00	4	196.4	25.13	37.6
			10	195.3	25.17	37.5
			26	204.6	18.75	29.8
1–8	Quaking	15.00	4	200.3	21.05	32.2
			10	199.5	23.19	35.3
			26	198.7	19.14	29.0

TABLE 11.—Permeability of Waterproofed Mortars

1 Part Portland Cement to 4 Parts Sand

No. of compound [26]	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given [m=moist]											
		Age 2 weeks			Age 4 weeks (retest)								
		10 minutes	30 minutes	1 hour	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
0	1	158	237	158	m	55	55	16	16	16	16	16	8
	2	m	118	118	m	m	16	16	24	16	16	24	16
	3	237	237	158	m	24	24	16	24	24	24	24	24
Average		132	197	145	m	26	32	16	21	19	19	21	16
32	1	174	142	142	0	0	m	m	m	m	8	8	8
	2	142	142	95	0	0	0	m	m	m	8	8	8
	3	237	197	158	8	8	16	24	16	32	24	24	16
Average		184	160	132	3	3	5	8	5	11	13	13	11
31	1	474	434	316	0	m	32	24	24	24	24	24	24
	2	158	158	158	0	m	71	63	55	55	55	47	47
	3	316	237	197	0	71	39	39	39	32	24	24	24
Average		316	276	224	0	24	47	42	39	37	34	32	32
33	1	0	m	39	m	m	m	16	16	8	8	8	8
	2	m	134	63	m	m	m	m	16	8	8	8	8
	3	205	142	103	m	m	8	16	16	16	8	8	8
Average		68	92	68	m	m	3	11	16	11	8	8	8
30	1	284	221	158	m	79	55	47	39	39	32	24	.....
	2	316	229	213	142	142	103	103	71	71	47	39	.....
	3	355	229	221	8	47	47	39	32	24	24	24	.....
Average		318	226	197	50	89	68	63	47	45	34	29	.....
29	1	24	87	63	0	0	m	8	8	8	8	8	8
	2	16	47	47	0	0	m	m	8	8	8	8	8
	3	213	213	190	m	8	8	8	8	16	16	16	16
Average		84	116	100	m	3	3	5	8	11	11	11	11
28	1	m	150	118	0	0	m	m	m	8	8	8	m [27]
	2	0	m	32	0	0	0	m	m	m	m	m	m [27]
	3	0	0	16	0	0	0	m	m	m	m	m	m [27]
Average		m	50	55	0	0	m	m	m	3	3	3	3
27a	1	237	197	197	95	111	95	63	55	47	47	47	32
	2	316	316	237	m	39	39	39	24	24	24	24	24
	3	237	197	158	47	103	63	71	63	55	47	55	47
Average		263	237	197	47	84	66	58	47	42	39	42	34
27b	1	0	0	m	0	0	0	0	0	0	0	m	8
	2	0	0	m	0	0	0	0	0	0	0	m	8
	3	0	0	m	0	0	0	0	0	0	0	0	m
Average		0	0	m	0	0	0	0	0	0	0	m	5

[26] See Table 23 for quantity and manner of incorporating each compound.
[27] After 24 hours all 3 test pieces were moist.

TABLE 11.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 4 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given [m=moist]											
		Age 2 weeks			Age 4 weeks (retest)								
		10 minutes	30 minutes	1 hour	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
37	1	166	111	71	m	39	47	24	24	16	16	8	8
	2	24	63	47	8	8	16	8	8	8	8	8	8
	3	m	32	47	0	0	0	0	0	0	0	0	0
Average		63	69	55	3	16	21	11	11	8	8	5	5
40 [28]	1	0	0	m	0	0	0	0	0	0	0	0	0
	2	0	0	m	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
Average		0	0	0	0	0	0	0	0	0	0	0	0
39	1	513	474	355	m	71	39	34	33	32	33	24	24
	2	513	474	395	m	55	39	33	32	32	32	24	24
	3	513	513	395	m	16	32	16	16	16	16	16	16
Average		513	487	382	m	47	37	29	29	27	27	21	21
38	1	474	395	237	32	79	71	47	32	24	24	24	24
	2	395	237	237	8	79	63	39	32	32	24	24	24
	3	395	237	237	47	63	55	32	32	32	32	32	32
Average		421	290	237	29	74	63	39	32	30	27	27	27
34	1	8	103	103	m	8	47	39	39	30	32	24	16
	2	m	8	63	m	m	8	32	32	32	24	24	24
	3	m	16	79	8	m	16	32	39	32	24	24	16
Average		3	42	83	3	3	24	34	37	34	27	24	19
35	1	276	205	150	8	24	47	55	47	47	47	47	39
	2	292	229	182	m	m	63	55	47	47	47	47	47
	3	348	261	126	m	m	24	39	32	32	32	32	24
Average		305	232	153	3	8	45	50	42	42	42	42	37
36	1	8	103	47	m	m	m	16	24	24	24	8	16
	2	47	53	79	m	m	m	8	m	8	8	m	8
	3	102	118	134	m	47	55	47	47	32	24	24	16
Average		53	95	87	m	16	18	24	24	21	19	11	13
23	1	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0	0
	3	0	0	0	0	0	0	0	0	0	0	0	0
Average		0	0	0	0	0	0	0	0	0	0	0	0

[28] Value unchanged up to 24 hours.

TABLE 11.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 4 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist.]										
		Age 13 weeks (retest)										
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours	48 hours
0	1	m	8	m	m	8	m	m	m	m	m	.....
	2	m	m	m	m	m	m	0	0	0	0	.....
	3	m	m	m	m	m	m	m	m	m	m	.....
Average	.....	m	3	m	m	3	m	m	m	m	m	.....
32	1	0	0	0	0	0	0	0	0	0	0	.....
	2	0	0	0	0	0	0	0	0	0	0	.....
	3	0	0	0	0	0	0	0	0	0	8	.....
Average	.....	0	0	0	0	0	0	0	0	0	3	.....
31	1	m	m	m	m	m	m	m	m	m	.....	.....
	2	m	m	0	0	0	0	0	0	0	.....	.....
	3	m	0	0	0	0	0	0	0	0	.....	.....
Average	.....	m	m	m	m	m	m	m	m	m	.....	.....
33	1	8	m	0	0	0	0	0	0	0	0	.....
	2	8	8	8	8	8	8	8	8	8	8	.....
	3	8	m	0	0	0	0	0	0	0	0	.....
Average	.....	8	3	3	3	3	3	3	3	3	3	.....
30	1	m	m	0	0	0	0	0	0	0	.....	.....
	2	m	m	0	0	0	0	0	0	0	.....	.....
	3	m	m	0	0	0	0	0	0	0	.....	.....
Average	.....	m	m	0	0	0	0	0	0	0	.....	.....
29	1	m	m	m	m	0	0	0	0	0	.....	.....
	2	m	m	8	m	m	m	m	m	0	.....	.....
	3	m	m	m	m	m	m	m	m	m	.....	.....
Average	.....	m	m	3	m	m	m	m	m	m	.....	.....
28	1	m	m	m	m	0	0	0	0	0	0	.....
	2	m	m	m	m	0	0	0	0	0	0	.....
	3	m	m	m	m	0	0	0	0	0	0	.....
Average	.....	m	m	m	m	0	0	0	0	0	0	.....
27a	1	m	m	m	8	8	8	8	8	8	.....	.....
	2	m	m	m	8	8	8	8	8	8	.....	.....
	3	m	m	m	8	8	8	8	8	8	.....	.....
Average	.....	m	m	m	8	8	8	8	8	8	.....	.....
27b	1	0	0	0	0	0	0	0	0	0	[29] 0	.....
	2	0	0	0	0	0	0	0	0	0	[29] 0	.....
	3	0	0	0	0	0	0	0	0	0	[29] 0	.....
Average	.....	0	0	0	0	0	0	0	0	0	[29] 0	.....

[29] Hydrostatic pressure raised to 2.8 at twenty-fourth hour and 4.2 at forty-eighth hour. All specimens still dry after 72 hours.

TABLE 11.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 4 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist.] Age 13 weeks (retest)										
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours	48 hours
37	1	m	m	m	m	m	0	0	0	0	0	.....
	2	m	m	m	m	m	0	0	0	0	0	.....
	5	m	m	m	m	m	0	0	0	0	0	.....
Average	.....	m	m	m	m	m	0	0	0	0	0	.....
40	1	m	m	m	m	m	m	m	m	m	m	.....
	2	m	m	m	m	m	m	m	m	m	m	.....
	3	m	m	m	m	m	m	m	m	m	m	.....
Average	.....	m	m	m	m	m	m	m	m	m	m	.....
39	1	m	m	m	m	m	m	m	m	m	m	.....
	2	m	m	m	m	m	m	8	8	m	8	.....
	3	m	m	m	m	m	m	m	m	m	m	.....
Average	.....	m	m	m	m	m	m	3	3	m	3	.....
38	1	m	m	m	m	m	m	m	m	m	m	.....
	2	m	m	m	m	m	m	m	m	m	m	.....
	3	m	8	8	8	8	8	m	m	m	m	.....
Average	.....	m	3	3	3	3	3	m	m	m	m	.....
34	1	24 hrs. pressure 1.4 kg.	0	24 hrs. pressure 2.8 kg.	m	24 hrs. pressure 4.2 kg.	m	24 hrs. pressure 5.6 kg.	m	.....	.....	.....
	2		0		0		0		m	.....	.....	.....
	3		0		0		0		0	.....	.....	.....
Average	.....	.....	0	.....	m	.....	m	.....	m	.....	.....	.....
35	1	24 hrs. pressure 1.4 kg.	0	24 hrs. pressure 2.8 kg.	0	24 hrs. pressure 4.2 kg.	m	.....	.....	.....	.....	.....
	2		0		0		m	.....	.....	.....	.....	.....
	3		0		0		m	.....	.....	.....	.....	.....
Average	.....	.....	0	.....	0	.....	m	.....	.....	.....	.....	.....
36	1	m	m	m	m	m	m	m	m	m	m	.....
	2	m	m	m	m	m	m	m	m	m	m	.....
	3	8	8	8	m	m	m	m	m	m	m	.....
Average	.....	3	3	3	m	m	m	m	m	m	m	.....
23[30]	1	m	m	m	m	m	m	m	m	m	m	.....
	2	m	m	m	m	m	m	m	m	m	m	.....
	3	m	m	m	m	m	m	m	m	m	0	.....
Average	.....	m	m	m	m	m	m	m	m	m	m	.....

[30] For this and succeeding tests in this set, pressure equals 2.8 kilograms.

TABLE 12.—Permeability of Waterproofed Mortars

1 Part Portland Cement to 4 Parts Sand

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface under designated pressure. [m = moist.]															
		26 weeks (retest)								52 weeks (retest)							
		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms	
		Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow
0	1				m								m		m		
	2				m								0		0		
	3				m								m		m		
Average				24	m							7	m	48	m		
32	1		0						0								0
	2		0						0								0
	3		0						m								0
Average		3	0					24	m							24	0
31	1				0		0		0		m		m		m		m
	2				16		8		8		0		0		0		0
	3				0		0		m		m		m		m		m
Average				7	5	24	3	24	3	24	m	4	m	7	m	7	m
33	1		0		0		0		0								m
	2		0		0		0		m								m
	3		0		0		0		0								m
Average		24	0	24	0	24	0	24	m							24	m
30	1		0		0		0		0								0
	2		0		0		0		m								0
	3		0		0		0		0								0
Average		24	0	24	0	24	0	24	m							7	0
29	1		0		0		0		0								0
	2		0		0		0		0								0
	3		0		0		0		0								0
Average		24	0	24	0	48	0	24	0							24	0
28	1		0		0		0		0								0
	2		0		0		0		0								0
	3		0		0		0		0								0
Average		24	0	24	0	24	0	24	0							24	0
27a	1		m		m								m		m		
	2		m		m								m		m		
	3		m		m								m		m		
Average		24	m	24	m							7	m	48	m		

TABLE 12.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 4 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface under designated pressure. [m = moist.]															
		26 weeks (retest)								52 weeks (retest)							
		1.4 Kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms	
		Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow
27b	1				0		0		0								
	2				0		0		0								
	3				0		0		0								
Average				24	0	24	0	48	0								
37	1		0		0		0		0								0
	2		0		0		m		m								m
	3		0		0		0		0								0
Average		24	0	24	0	24	m	24	m							6	m
40	1		0		0		0		0								8
	2		0		0		0		0								m
	3		0		0		0		0								0
Average		24	0	24	0	24	0	24	0							6	3
39	1		0		0		0		0								24
	2		0		0		0		0								47
	3		0		0		m		m								m
Average		24	0	24	0	24	m	24	m							6	24
38	1		0		0		m		m								m
	2		0		0		0		0								m
	3		0		0		0		0								m
Average		24	0	24	0	24	m	24	m							48	m
34	1		24														
	2		0														
	3		47														
Average		7	24														
35	1						0		0								
	2						0		0								
	3						0		m								
Average						1	0	24	m								
36	1		0														
	2		0														
	3		16														
Average		7	5														
25	1								0								0
	2								0								0
	3								0								0
Average								72	0							48	0

TABLE 13.—Permeability of Waterproofed Mortars

1 Part Portland Cement to 6 Parts Sand

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist]										
		Age 2 weeks			Age 4 weeks (retest)							
		10 minutes	30 minutes	1 hour	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
0	1	2130	1820	1580	434	379	355	316	284	292	276	237	213
	2	1820	1580	1420	316	237	197	174	158	166	158	150	134
	3	948	869	790	237	197	197	158	126	142	126	118	111
Average		1633	1423	1263	329	271	250	216	189	200	187	168	153
32	1	2530	1820	1420	592	434	340	276	253	237	197	158	118
	2	1660	1300	1030	316	316	237	237	158	158	118	95	79
	3	1740	1420	1110	355	316	253	237	197	158	118	95	79
Average		1980	1510	1190	421	355	277	250	203	184	144	116	92
31	1	1820	1660	1420	553	395	395	316	197	142	150	126	103
	2	1180	1030	948	237	197	182	142	126	79	71	63	55
	3	1180	1030	1030	474	284	213	205	197	158	166	150	134
Average		1390	1240	1130	421	292	263	221	173	126	129	113	97
33	1	632	553	474	158	197	197	197	118	79	55	47	32
	2	1030	869	790	276	276	276	197	158	158	134	118	134
	3	790	671	592	237	237	237	197	158	158	118	95	118
Average		817	698	619	224	237	237	197	145	132	102	87	95
30	1	632	632	553	142	118	95	79	79	79	71	71	63
	2	395	355	316	134	95	79	71	63	55	55	55	55
	3	553	529	474	142	103	103	87	87	87	87	87	87
Average		527	505	448	139	105	92	79	76	74	71	71	68
29	1	1260	1030	869	197	158	142	134	134	126	118	118	118
	2	711	632	553	213	158	126	134	126	111	111	103	103
	3	1180	869	790	197	158	142	142	126	126	126	118	126
Average		1050	844	737	202	158	137	137	129	121	118	113	116
28	1	553	513	395	m	118	111	87	79	79	71	71	63
	2	395	316	316	111	111	95	87	71	87	79	71	63
	3	395	316	237	m	55	39	39	32	24	24	24	24
Average		448	382	316	37	95	82	71	61	63	58	55	50
27a	1	790	711	711	316	316	316	237	237	197	118	118	118
	2	790	711	711	276	276	237	158	197	118	79	79	79
	3	948	869	869	434	395	316	276	237	197	158	158	158
Average		843	764	764	342	329	290	224	224	171	118	118	118
27b	1	276	276	237	0	103	87	71	63	55	55	55	55
	2	237	237	237	0	111	103	79	79	95	87	79	71
	3	276	197	197	0	103	87	55	55	79	55	50	39
Average		263	237	224	0	106	92	68	65	76	66	58	55

TABLE 13.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 6 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist.]											
		Age 2 weeks			Age 4 weeks (retest)								
		10 minutes	30 minutes	1 hour	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
37	1	632	395	355	16	71	39	24	24	24	32	24	24
	2	395	395	355	m	95	63	63	63	55	55	47	47
	3	395	395	355	0	24	71	39	39	39	32	24	24
Average		474	395	355	5	63	58	42	42	39	40	32	32
40	1	158	142	111	m	8	32	32	16	16	16	16	16
	2	276	276	213	8	39	79	79	55	55	55	55	55
	3	118	87	71	m	m	8	8	8	8	8	8	8
Average		184	168	132	3	16	40	40	26	26	26	26	26
33	1	3240	2530	2210	355	395	316	237	197	197	197	158	158
	2	4500	3000	2370	355	434	395	316	276	276	276	237	197
	3	3160	2530	2130	474	513	434	355	316	316	316	276	237
Average		3630	2690	2240	395	447	382	303	263	263	263	224	197
38	1	2690	2130	1580	553	474	395	355	316	276	276	276	276
	2	1620	1500	1110	395	355	276	276	237	237	237	237	237
	3	2370	2050	1580	474	434	316	316	276	237	237	276	237
Average		2290	1890	1420	474	421	329	316	276	250	250	263	250
34	1	600	521	490	395	332	261	221	190	158	142	134	111
	2	395	348	324	150	134	126	103	118	103	95	95	87
	3	774	664	553	118	79	79	55	55	55	39	47	39
Average		590	511	456	221	182	155	126	121	105	92	92	79
35	1	711	592	442	m	103	87	95	87	79	87	95	95
	2	466	316	237	m	24	71	71	63	63	47	47	47
	3	924	727	585	m	142	126	95	87	118	118	111	111
Average		700	545	421	m	90	95	87	79	87	84	84	84
36	1	521	427	348	16	79	63	55	39	39	24	32	24
	2	466	353	340	182	150	87	71	63	47	24	47	32
	3	490	419	379	71	63	55	24	24	24	16	24	24
Average		492	400	356	90	97	68	50	42	37	21	34	27

TABLE 13.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 6 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m = moist.]									
		Age 13 weeks (retest)									
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
0	1	24	95	71	47	47	47	32	32	32	.....
	2	8	m	8	16	16	16	16	16	16	.....
	3	0	m	8	16	16	16	8	8	8	.....
Average	.....	11	32	29	26	26	26	19	19	19	.....
32	1	m	m	m	24	16	16	16	16	16	.....
	2	m	m	m	8	16	24	16	16	16	.....
	3	0	m	m	m	m	m	8	16	16	.....
Average	.....	m	m	m	11	11	13	13	16	16	.....
31	1	m	m	8	8	16	8	16	8	8	.....
	2	m	m	m	0	0	0	0	0	0	.....
	3	m	m	8	8	8	8	8	8	8	.....
Average	.....	m	m	5	5	8	5	8	5	5	.....
33	1	0	m	m	m	m	m	m	m	8	.....
	2	0	m	m	m	8	8	8	8	8	.....
	3	0	m	m	m	8	8	8	16	8	.....
Average	.....	0	m	m	m	5	5	5	8	8	.....
30	1	m	m	8	8	8	8	16	16	16	.....
	2	m	m	8	8	m	8	24	24	24	.....
	3	m	m	8	m	8	8	m	8	8	.....
Average	.....	m	m	8	5	5	8	13	16	16	.....
29	1	m	8	8	8	24	8	8	8	8	.....
	2	m	m	8	24	24	16	16	16	16	.....
	3	m	m	8	16	16	16	16	24	8	.....
Average	.....	m	3	8	16	21	13	13	16	11	.....
28	1	m	m	m	8	8	8	8	8	m	8
	2	m	m	m	m	8	8	m	8	m	m
	3	8	m	m	m	8	m	m	m	m	m
Average	.....	3	m	m	3	8	5	3	5	m	3
27a	1	m	m	m	8	8	m	8	m	8	.....
	2	m	m	m	8	8	8	8	8	8	.....
	3	m	m	m	8	8	8	8	8	8	.....
Average	.....	m	m	m	8	8	5	8	5	8	.....
27b	1	0	0	0	0	0	0	0	m	m	.....
	2	0	0	0	0	0	0	0	m	m	.....
	3	0	0	0	0	m	4	8	8	8	.....
Average	.....	0	0	0	0	m	1	3	3	3	.....

TABLE 13.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 6 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist.] Age 13 weeks (retest)									
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
37	1	m	m	m	m	m	m	m	m	m	m
	2	m	m	16	16	24	24	16	8	16	m
	3	m	m	m	m	m	m	m	8	m	m
Average		m	m	5	5	8	8	5	5	5	m
40	1	m	0	0	0	0	0	0	0	0	[a] 0
	2	m	8	8	24	24	16	8	16	16	[a] 8
	3	8	m	0	0	0	0	0	0	0	[a] 0
Average		3	3	3	8	8	5	3	5	5	[a] 3
33	1	m	55	32	24	32	24	32	24	16	.....
	2	m	m	m	m	8	8	24	16	8	.....
	3	m	m	m	m	m	m	8	8	m	.....
Average		m	18	11	8	16	11	24	16	8	.....
32	1	m	8	m	8	8	8	8	8	8	.....
	2	16	8	m	8	16	8	8	8	8	.....
	3	m	8	8	16	16	16	8	8	8	.....
Average		8	8	3	11	13	11	8	8	8	.....
34	1	m	m	m	8	32	16	16	24	16	.....
	2	m	m	m	8	8	8	8	8	16	.....
	3	m	m	m	m	m	m	8	8	8	.....
Average		m	m	m	8	13	8	11	13	13	.....
35	1	m	m	m	m	m	8	16	8	8	.....
	2	m	m	m	m	m	m	m	m	m	.....
	3	m	8	8	m	m	8	m	m	8	.....
Average		m	8	8	m	m	5	5	3	5	.....
36	1	m	m	m	m	m	m	m	m	m	.....
	2	m	m	m	m	m	m	m	m	m	.....
	3	m	m	m	m	m	m	m	m	m	.....
Average		m	m	m	m	m	m	m	m	m	.....

[a] Hydrostatic pressure raised to 2.8 kilograms at twenty-fourth hour. At thirty-second hour Nos. 1 and 3 were "Moist" and No. 2 passed 24 tenths cubic millimeters.

TABLE 14.—Permeability of Waterproofed Mortars

1 Part Portland Cement to 6 Parts Sand

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface under designated pressure. [m=moist.]															
		26 weeks (retest)								52 weeks (retest)							
		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms	
		Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow
0	1	.....	8	.....	.....	.....	.....	.....	.....	.....	8	.....	.....	.....	.....	.....	.....
	2	.....	8	.....	.....	.....	.....	.....	.....	.....	m	.....	.....	.....	.....	.....	.....
	3	.....	24	.....	.....	.....	.....	.....	.....	.....	m	.....	.....	.....	.....	.....	.....
Average		.....	7	.....	.....	.....	.....	.....	.....	24	3	.....	.....	.....	.....	.....	.....
32	1	.....	16	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
	2	.....	16	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
	3	.....	m	.....	.....	.....	.....	.....	.....	.....	4	.....	8	.....	4	.....	4
Average		.....	7	.....	11	.....	.....	.....	.....	24	1	24	3	24	1	7	1
31	1	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	m
	2	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
	3	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	0
Average		.....	24	m	24	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	7	m
33	1	.....	24	.....	.....	.....	.....	.....	.....	.....	m	.....	m	.....	m	.....	m
	2	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
	3	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	m	.....	m
Average		.....	12	8	.....	.....	.....	.....	.....	24	m	24	m	24	m	7	m
30	1	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	m	.....	m
	2	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	m	.....	8	.....	8
	3	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
Average		.....	24	m	.....	.....	.....	.....	.....	3	0	20	m	24	8	7	3
29	1	.....	0	.....	m	.....	.....	.....	.....	.....	.....	.....	m	.....	m	.....	.....
	2	.....	0	.....	0	.....	.....	.....	.....	.....	.....	.....	m	.....	8	.....	.....
	3	.....	0	.....	m	.....	.....	.....	.....	.....	.....	.....	m	.....	8	.....	.....
Average		.....	24	0	48	m	.....	.....	.....	.....	.....	24	m	7	5	.....	.....
28	1	.....	m	.....	m	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	0
	2	.....	0	.....	0	.....	0	.....	m	.....	.....	.....	.....	.....	.....	.....	47
	3	.....	0	.....	0	.....	0	.....	m	.....	.....	.....	.....	.....	.....	.....	16
Average		.....	24	m	24	m	24	m	24	m	.....	.....	.....	.....	.....	.....	6	21
27a	1	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
	2	.....	0	.....	.....	.....	.....	.....	.....	.....	0	.....	m	.....	m	.....	m
	3	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
Average		.....	24	m	.....	.....	.....	.....	.....	24	0	24	m	7	m	7	m
27b	1	.....	.....	.....	0	.....	m	.....	0	.....	.....	.....	.....	.....	.....	.....	0
	2	.....	.....	.....	0	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	0
	3	.....	.....	.....	0	.....	m	.....	0	.....	.....	.....	.....	.....	.....	.....	0
Average		.....	.....	.....	24	0	48	m	48	m	.....	.....	.....	.....	.....	7	0

TABLE 14.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 6 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface under designated pressure. [m=moist.]															
		26 weeks (retest)								52 weeks (retest)							
		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms		1.4 kilograms		2.8 kilograms		4.2 kilograms		5.6 kilograms	
		Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow	Hours	Flow
37	1	.....	0	.....	0	.....	0	.....	m	.....	.....	.....	.....	.....	.....	.....	m
	2	.....	0	.....	0	.....	m	.....	0	.....	.....	.....	.....	.....	.....	.....	16
	3	.....	0	.....	0	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	m
Average		24	0	24	0	24	m	24	m	.....	.....	.....	.....	.....	.....	30	5
40	1	.....	0	.....	0	.....	m	.....	0	.....	0	.....	m	.....	m	.....	m
	2	.....	0	.....	m	.....	m	.....	m	.....	m	.....	.....	.....	32	.....	8
	3	.....	0	.....	0	.....	0	.....	0	.....	0	.....	m	.....	m	.....	m
Average		24	0	24	m	24	m	24	m	24	m	24	m	24	11	48	3
39	1	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
	2	.....	m	.....	.....	.....	.....	.....	.....	.....	0	.....	0	.....	0	.....	0
	3	.....	m	.....	.....	.....	.....	.....	.....	.....	16	.....	24	.....	47	.....	32
Average		24	m	.....	.....	.....	.....	.....	.....	24	5	24	8	4	16	6	11
38	1	.....	0	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	32	.....	.....
	2	.....	m	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	2	.....	.....
	3	.....	m	.....	m	.....	m	.....	.....	.....	.....	.....	.....	.....	8	.....	.....
Average		24	m	24	m	24	m	.....	.....	.....	.....	.....	.....	24	16	.....	.....
34	1	.....	16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average		7	5	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
35	1	.....	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	.....	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average		24	m	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
36	1	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	2	.....	0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	3	.....	8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average		24	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE 15.—Permeability of Waterproofed Mortars

1 Part Portland Cement to 8 Parts Sand

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given.											
		Age, 2 weeks			Age, 4 weeks (retest)								
		10 minutes	30 minutes	1 hour	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
0	1	5530	4420	3790	2760	1820	1420	1260	1260	1030	1030	908	790
	2	3320	2840	2450	869	790	632	513	513	474	434	434	395
	3	4980	4110	3790	1580	1420	948	869	869	790	753	711	711
Average		4610	3790	3343	1736	1343	1000	881	881	765	739	684	632
32	1	1970	1820	1580	474	474	355	355	316	276	237	237	237
	2	2840	2610	2290	711	632	553	513	513	474	474	474	395
	3	3950	3550	3000	1030	948	790	711	671	592	474	434	474
Average		2920	2660	2290	738	685	565	526	500	447	395	382	369
31	1	3790	3480	3000	1110	869	711	671	592	474	474	434	395
	2	3480	3240	2760	632	553	513	434	395	316	316	316	276
	3	3480	3160	2610	869	711	671	592	513	474	474	395	316
Average		3580	3290	2790	870	711	632	566	500	421	421	382	329
33	1	3710	2920	2610	1110	948	869	711	632	632	592	434	.....
	2	3320	2690	2690	948	790	671	553	553	513	474	474	.....
	3	2210	1820	1500	632	553	474	474	355	316	316	316	.....
Average		3080	2480	2270	897	764	671	579	513	487	461	408	.....
30	1	2920	2840	2210	948	869	711	671	632	632	553	553	513
	2	3160	2840	2290	790	750	711	632	592	592	553	553	474
	3	1340	1340	1180	474	434	395	355	395	355	355	355	316
Average		2470	2340	1890	737	684	606	553	540	526	487	487	434
29	1	2130	1970	1580	474	513	395	395	395	395	355	395	355
	2	1900	1740	1500	513	434	434	395	355	395	395	395	355
	3	2530	2290	1970	553	790	671	632	553	592	553	553	553
Average		2190	2000	1680	513	579	500	474	434	461	434	448	421
28	1	2450	1740	1420	1150	987	987	908	790	750	750	671	632
	2	1660	1340	1180	869	790	711	711	632	632	592	632	632
	3	2840	2130	1970	1420	1260	1260	1180	1110	987	1030	987	948
Average		2320	1740	1520	1146	1012	986	933	844	790	791	763	737
27a	1	3550	3080	2920	1260	1180	1150	987	948	829	790	869	750
	2	3710	3160	3000	1260	1110	1030	948	869	790	790	790	711
	3	3710	3400	3160	1260	1220	1110	987	869	948	869	869	869
Average		3657	3213	3027	1260	1170	1097	974	895	856	816	843	777
27b	1	1180	869	790	529	308	269	174	174	166	150	150	142
	2	1110	790	711	513	316	276	221	205	190	174	150	166
	3	948	869	711	482	379	363	316	300	276	276	269	253
Average		1079	843	737	508	334	303	204	226	211	200	190	187

TABLE 15.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given.											
		Age, 2 weeks			Age, 4 weeks (retest)								
		10 minutes	30 minutes	1 hour	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
37	1	2370	2210	2050	790	750	592	513	513	513	434	395	395
	2	2210	2050	1740	829	790	711	671	671	632	553	553	553
	3	1970	2130	1580	513	395	395	355	316	316	276	316	276
Average		2180	2130	1790	711	645	566	513	500	487	421	421	408
40	1	790	632	474	118	118	103	87	71	55	71	71	71
	2	1000	869	790	395	355	316	261	221	221	221	197	197
	3	553	395	316	158	95	86	86	71	71	71	71	71
Average		791	632	527	224	189	168	145	121	116	121	113	113
39	1	1.3000	1.1800	0.9480	3160	3240	2920	2210	2290	2210	2130	1820	1420
	2	1.6200	1.3800	1.0700	3550	3550	2920	2130	2210	2130	2130	1900	1340
	3	8090	7900	7110	1420	1740	1500	1420	1420	1340	1340	1260	1110
Average		1.2630	1.1170	9100	2710	2840	2450	1920	1970	1890	1870	1660	1290
38	1	5920	3950	3790	1900	1660	1340	790	790	790	790	790	790
	2	5530	4180	3790	2130	1740	1260	790	750	790	790	790	790
	3	6320	4740	4190	2450	1970	1260	790	711	750	750	790	790
Average		5920	4290	3920	2160	1790	1290	790	750	780	780	790	790
34	1	4813	3870	3002	806	687	548	490	411	585	474	395	348
	2	3712	3317	2844	553	553	495	363	284	419	316	369	213
	3	3317	2765	2765	592	529	498	371	316	474	371	276	221
Average		3949	3317	2870	650	590	542	408	337	493	387	313	261
35	1	3049	2528	2409	687	671	506	253	205	174	142	126	118
	2	1998	1698	1769	387	340	308	197	158	118	95	87	79
	3	2930	2457	2117	860	687	474	276	245	213	166	102	134
Average		2659	2228	2098	648	566	429	242	203	168	134	132	110
36	1	2148	1777	1817	332	229	213	150	142	118	118	111	103
	2	2377	2077	1959	379	261	190	158	142	118	103	95	95
	3	2014	1777	1777	324	213	190	166	118	103	111	103	95
Average		2180	1877	1851	345	234	198	158	134	113	111	103	98

TABLE 15.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 3 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist.]								
		Age, 13 weeks (retest)								
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
0	1	142	118	118	126	103	87	87	79	71
	2	24	87	79	63	55	71	55	63	39
	3	79	79	63	55	47	55	39	55	24
Average		82	95	87	81	68	71	60	66	45
32	1	m	m	32	39	24	39	32	55	16
	2	m	39	47	39	47	47	55	55	39
	3	m	47	71	55	47	47	39	50	47
Average		m	29	50	44	39	44	42	50	34
1	1	m	87	79	55	55	55	55	55	55
	2	m	79	71	63	55	55	47	63	63
	3	m	63	55	55	39	39	39	39	32
Average		m	76	68	58	50	50	47	52	50
33	1	8	197	79	71	63	55	55	55	47
	2	39	126	103	87	87	79	63	87	47
	3	m	8	32	8	8	8	32	16	8
Average		16	110	71	55	53	47	50	53	34
30	1	m	103	87	55	95	87	87	79	71
	2	m	87	111	55	103	87	87	63	55
	3	m	190	87	47	79	79	79	63	63
Average		m	127	95	52	92	84	84	68	63
29	1	m	95	126	79	79	71	58	79	63
	2	m	11	158	150	158	150	142	134	111
	3	8	142	158	142	142	134	134	126	118
Average		3	53	147	124	126	118	113	113	97
28	1	m	79	87	87	79	103	87	87	71
	2	m	m	79	55	63	87	71	71	71
	3	71	103	103	87	103	103	95	95	79
Average		24	61	90	76	82	98	94	94	74
27a	1	m	87	79	71	71	71	71	63	63
	2	m	103	103	95	87	95	71	71	63
	3	m	95	103	95	87	103	79	71	71
Average		m	95	95	87	82	90	74	68	66
27b	1	m	m	32	39	39	32	32	32	24
	2	m	m	24	47	39	32	32	32	24
	3	m	m	55	63	39	32	32	32	32
Average		m	m	37	50	39	32	32	32	27

TABLE 15.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand—Continued

No. of compound	Test piece No.	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the periods given. [m=moist.]								
		Age, 13 weeks (retest)								
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours
37	1	142	134	111	103	103	95	95	95	79
	2	m	m	32	63	24	24	24	32	24
	3	m	m	m	24	8	8	8	8	16
Average		47	45	48	63	45	42	42	45	40
40	1	m	134	55	55	47	47	55	47	24
	2	m	m	63	55	47	47	47	80	24
	3	m	m	32	39	39	24	16	32	24
Average		m	45	50	50	44	39	36	39	24
39	1	221	158	134	126	95	87	79	87	87
	2	284	190	197	182	158	150	134	126	95
	3	182	95	103	111	111	103	87	87	71
Average		229	148	145	140	121	113	100	100	84
38	1	118	71	55	47	32	32	32	24	16
	2	m	16	39	32	16	16	16	8	16
	3	142	95	79	55	47	55	39	39	24
Average		87	61	58	45	32	34	29	24	19
34	1	m	111	111	87	79	63	55	55	63
	2	m	87	111	95	87	79	79	79	79
	3	m	m	118	89	39	32	32	32	24
Average		m	66	113	74	61	58	55	55	55
35	1	m	m	55	47	39	32	32	32	24
	2	m	m	16	32	24	32	24	32	16
	3	m	m	95	59	32	32	32	32	24
Average		m	m	55	39	31	32	30	32	21
36	1	m	m	m	m	16	16	16	16	16
	2	m	m	m	m	16	16	16	16	16
	3	m	m	m	m	16	16	16	16	16
Average		m	m	m	m	16	16	16	16	16

TABLE 16.—Permeability of Waterproofed Mortars

1 Part Portland Cement to 8 Parts Sand

No. of compound	Test piece number	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of periods given. [m=moist.]									
		26 weeks (Retest)									
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
0	1	32	87	79	79	79	71	71	63	55	.....
	2	m	87	79	24	24	24	24	8	16	.....
	3	8	8	8	24	24	24	24	8	16	.....
Average		13	61	55	42	42	40	40	26	29	.....
32	1	m	m	m	m	16	8	m	8	8	m
	2	m	m	m	m	8	71	8	8	8	m
	3	m	m	47	24	32	24	16	16	16	8
Average		m	m	16	8	19	34	8	11	11	8
31	1	m	39	55	47	39	39	39	39	47	.....
	2	m	m	m	47	32	16	16	24	16	.....
	3	m	m	55	47	47	39	39	39	47	.....
Average		m	13	37	47	39	31	31	34	37	.....
33	1	m	8	8	8	16	16	8	8	16	.....
	2	m	16	24	32	32	24	32	32	24	.....
	3	m	8	m	m	8	8	8	8	16	.....
Average		m	11	11	13	19	16	16	16	19	.....
30	1	m	m	m	32	24	24	16	16	16	.....
	2	m	m	m	16	24	24	16	32	24	.....
	3	m	m	8	24	16	8	8	m	8	.....
Average		m	m	8	24	21	19	13	16	16	.....
29	1	m	8	8	16	16	16	8	8	16	.....
	2	m	m	m	m	8	8	8	8	8	.....
	3	m	8	m	8	16	16	16	8	16	.....
Average		m	5	8	8	13	13	11	8	13	.....
28	1	m	m	39	32	32	39	47	32	24	.....
	2	m	m	47	55	47	39	47	39	32	.....
	3	m	m	63	63	55	55	47	55	32	.....
Average		m	m	50	50	45	44	47	42	29	.....
27a	1	m	8	8	24	24	16	16	16	8	.....
	2	m	8	24	24	32	32	24	24	24	.....
	3	m	m	16	16	24	24	8	24	16	.....
Average		m	5	16	21	27	24	16	21	16	.....
27b	1	m	m	8	16	16	16	16	16	16	.....
	2	m	8	m	8	m	m	m	m	m	.....
	3	m	m	m	m	m	m	8	8	8	.....
Average		m	8	3	8	5	5	8	8	8	.....

TABLE 16.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand—Continued

No. of compound	Test piece number	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of periods given. [m=moist.]									
		26 weeks (Retest)									
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
37	1	m	m	m	m	24	16	16	16	m	m
	2	m	m	m	8	8	24	16	8	8	m
	3	m	m	m	m	m	m	m	m	m	m
Average		m	m	m	3	11	13	11	8	3	m
40	1	8	8	m	8	8	16	8	16	16	.....
	2	m	m	m	8	16	16	16	16	8	.....
	3	m	m	m	m	8	m	m	16	m	.....
Average		3	3	m	5	11	11	8	16	8	.....
39	1	316	93	87	79	63	55	39	39	32	.....
	2	340	229	190	158	126	95	95	95	79	.....
	3	355	63	55	47	47	39	32	32	32	.....
Average		337	129	111	95	79	63	55	55	48	.....
38	1	m	m	24	24	16	16	8	16	16	.....
	2	8	111	32	39	24	24	16	24	16	.....
	3	m	16	24	16	16	16	16	16	16	.....
Average		3	42	27	26	19	19	13	19	16	.....
34	1	m	m	95	55	63	71	55	71	79	.....
	2	m	m	71	95	39	39	32	32	32	.....
	3	m	m	m	m	m	m	m	16	8	.....
Average		m	m	55	50	34	37	29	40	40	.....
35	1	.....	m	m	39	47	47	32	39	39	.....
	2	.....	m	m	55	39	55	47	47	47	.....
	3	.....	237	237	253	213	190	182	174	166	.....
Average		.....	79	79	116	100	97	87	87	84	.....
36	1	0	0	0	0	0	m	m	m	m	8
	2	0	0	0	0	0	m	39	20	16	16
	3	0	0	0	m	m	m	32	m	16	16
Average		0	0	0	m	m	m	24	7	11	13

TABLE 16.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand—Continued

No. of compound	Test piece number	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of periods given. [m=moist.]									
		52 weeks									
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
0	1	m	m	m	m	8	16	32	24	8	.....
	2	0	0	0	0	0	0	m	m	m	.....
	3	0	0	0	0	0	0	0	0	0	.....
Average	.....	m	m	m	m	3	5	11	8	3	.....
32	1	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	m	m	m	m
	3	0	0	0	0	0	0	0	0	0	0
Average	.....	0	0	0	0	0	0	m	m	m	m
31	1	0	m	m	m	32	39	39	39	39	32
	2	0	0	0	0	m	m	m	m	m	8
	3	0	0	0	0	m	m	m	m	m	m
Average	.....	0	m	m	m	11	13	13	13	13	13
33	1	0	0	0	m	m	m	m	m	m	m
	2	0	0	m	m	m	24	16	8	16	8
	3	0	0	0	0	0	m	m	m	m	m
Average	.....	0	0	m	m	m	8	5	3	5	3
30	1	m	m	m	m	m	16	8	.....	.....	8
	2	m	m	m	m	m	m	m	.....	.....	m
	3	0	0	0	m	m	m	m	.....	.....	8
Average	.....	m	m	m	m	m	5	3	.....	.....	5
29	1	0	0	0	0	0	0	0	.....	.....	m
	2	m	m	m	0	0	0	0	.....	.....	16
	3	0	0	m	m	16	16	16	.....	.....	32
Average	.....	m	m	m	m	5	5	5	.....	.....	16
28	1	0	0	0	m	m	m	.....	.....	.....	16
	2	m	87	111	126	126	118	.....	.....	.....	47
	3	0	m	m	m	8	8	.....	.....	.....	8
Average	.....	m	29	37	42	45	42	.....	.....	.....	24
27a	1	0	m	m	m	m	8	16	8	8	8
	2	0	m	m	m	32	32	32	32	32	16
	3	m	39	95	95	95	87	79	79	79	32
Average	.....	m	13	32	32	42	42	43	40	40	19
27b	1	m	m	0	0	0	0	0	0	0	.....
	2	m	m	m	0	0	0	0	0	0	.....
	3	m	m	m	24	32	24	24	16	16	.....
Average	.....	m	m	m	8	11	8	8	5	5	.....

TABLE 16.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand—Continued

No. of compound	Test piece number	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of periods given. [m=moist.]									
		52 weeks									
		10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
37	1	0	8	16	32	24	32	8	.....	8	8
	2	0	0	0	0	0	0	0	.....	0	8
	3	m	m	m	m	m	m	m	.....	m	m
Average	.....	m	3	5	11	8	11	3	.....	3	5
40	1	0	0	0	m	m	16	8	8	8	16
	2	0	0	m	m	m	m	m	8	8	8
	3	0	0	0	0	m	m	m	m	m	m
Average	.....	0	0	m	m	m	5	3	5	5	8
39	1	0	0	0	0	m	m	.....	m	.....	.....
	2	0	0	0	m	32	32	.....	32	.....	24
	3	0	0	0	m	m	m	.....	8	.....	4
Average	.....	0	0	0	m	11	11	.....	13	.....	14
38	1	0	0	0	m	32	32	.....	32	.....	8
	2	0	0	0	m	32	32	.....	32	.....	8
	3	0	0	0	m	m	m	.....	0	.....	0
Average	.....	0	0	0	m	21	26	.....	26	.....	5

TABLE 16.—Permeability of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand—Continued

No. of compound	Test piece number	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of periods given. [m=moist.]										
		52 weeks (Retest)										
		Pressure raised to—	10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
0	1	2.8 kilograms	m	8	24	32	32	32	.....	.....	.....	.....
	2		m	m	m	m	m	m	.....	.....	.....	.....
	3		0	0	0	0	0	0	.....	.....	.....	.....
Average	.....		m	3	8	11	11	11	.....	.....	.....	.....
32	1	5.6 kilograms	m	m	m	m	m	m	m	m	m	.....
	2		m	m	m	8	24	16	8	16	16	.....
	3		m	m	m	m	m	8	8	8	m	.....
Average	.....		m	m	m	3	8	8	5	8	5	.....
33	1	2.8 kilograms	m	16	16	24	63	39	24	32	32	.....
	2		16	32	55	63	63	63	47	47	71	.....
	3		m	8	16	16	8	8	32	16	32	.....
Average	.....		5	19	29	34	45	37	34	32	45	.....
30	1	2.8 kilograms	24	47	.....	.....	.....	.....	.....	.....	.....	.....
	2		24	32	.....	.....	.....	.....	.....	.....	.....	.....
	3		16	16	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....		21	32	.....	.....	.....	.....	.....	.....	.....	.....
29	1	2 8 kilograms	m	24	.....	.....	.....	.....	.....	.....	.....	.....
	2		16′	24	.....	.....	.....	.....	.....	.....	.....	.....
	3		87	87	.....	.....	.....	.....	.....	.....	.....	.....
Average	.....		34	45	.....	.....	.....	.....	.....	.....	.....	.....
37	1	2.8 kilograms	m	24	39	32	24	24	.....	16	32	24
	2		8	m	8	8	8	8	.....	8	8	8
	3		m	16	8	8	m	m	.....	m	m	m
Average	.....		3	13	18	16	11	11	.....	8	13	11
40	1	2.8 kilograms	16	24	16	32	24	32	24	24	32	24
	2		8	16	16	16	16	16	16	8	16	16
	3		m	m	16	8	8	m	8	8	8	m
Average	.....		8	13	16	19	16	16	16	13	19	13
39	1	2.8 kilograms	m	m	m	m	m	16	8	8	8	m
	2		95	63	71	79	95	71	71	63	63	47
	3		8	16	16	16	24	16	16	16	16	47
Average	.....		34	26	29	32	40	34	32	29	29	31
38	1	2.8 kilograms	8	16	16	16	24	24	24	16	24	16
	2		8	16	16	32	39	32	16	32	24	16
	3		0	0	0	0	0	m	m	m	m	32
Average	.....		5	11	11	16	21	19	13	16	16	21

TABLE 17.—Effect of "Retesting" on Permeability

1 Part Portland Cement to 4 Parts Sand

No. of test piece	Age in weeks when tested	Test or retest	Tenths of a cubic millimeter of water passed per minute per square centimeter of surface subjected to 1.4 kilograms hydrostatic pressure. One-minute readings taken at the end of the following periods. [m=moist.]									
			10 minutes	30 minutes	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours	7 hours	24 hours
1	2	Test	87	103	87							
2	2	...do	245	182	150							
3	2	...do	221	134	111							
Average			184	140	116							
4	4	Test	m	m	8	16	24	16	16	16	8	m
5	4	...do	m	m	47	40	32	24	24	24	24	8
6	4	...do	m	79	47	55	32	32	24	32	24	8
Average			m	86	34	37	29	24	21	24	17	5
1	4	Retest	m	8	m	m	8	m	8	8	8	m
2	4	...do	16	8	m	m	8	m	16	8	8	m
3	4	...do	m	16	16	32	16	16	24	16	16	8
Average			5	11	5	11	11	5	16	11	11	3
7	13	Test	m	m	m	m	m	m	m	m	m	m
8	13	...do	m	m	m	m	m	m	m	m	m	m
9	13	...do	m	m	m	m	0	0	0	0	0	m
Average			m	m	m	m	m	m	m	m	m	m
1	13	Retest	m	m	m	m	m	m	m	m		
2	13	...do	8	8	m	m	m	m	0	0		
3	13	...do	m	m	m	m	0	0	0	0		
Average			3	3	m	m	m	m	m	m		
4	13	Retest	m	m	m	m	m	m	m	0		
5	13	...do	m	m	m	m	m	m	m	0		
6	13	...do	m	m	m	m	m	m	m	0		
Average			m	m	m	m	m	m	m	0		
10	26	Test	0	0	0	0	0	0	0	0	0	0
11	26	...do	0	m	m	m	m	m	m	24	16	8
12	26	...do	0	m	m	m	m	m	m	m	m	m
Average			0	m	m	m	m	m	m	8	5	3
1 [23]	26	Retest	m	0	0	0	0	[23] 0	[23] m			[23] m
2	26	...do	0	0	0	0	0	[23] 0	[23] 0			[23] 0
3	26	...do	m	0	0	0	0	[23] 0	[23] 0			[23] 0
Average			m	0	0	0	0	[23] 0	[23] m			[23] m
4	26	Retest	0	0	0	0	0	[23] 0	[23] 0			[23] 0
5	26	...do	0	0	0	0	0	[23] 0	m			[23] m
6	26	...do	0	0	0	0	0	[23] 0	m			[23] m
Average			0	0	0	0	0	[23] 0	m			[23] m
7	26	Retest	0	0	0	0	m	m	m	m	m	m
8	26	...do	0	0	0	0	0	0	0	0	0	m
9	26	...do	0	0	0	0	0	0	0	0	m	m
Average			0	0	0	0	m	m	m	m	m	m

[23] Test pieces 1 to 6, inclusive, were retested at the 26-week period under 4.2 and 5.6 kg. per sq. cm. hydrostatic pressure, with the following results:

Pressure, 4.2 kg.; time, 24 hours: Test piece number—1 moist, 2 dry, 3 dry, average moist; 4 dry, 5 moist, 6 moist, average moist. Pressure, 5.6 kg.; time, 24 hours: Test piece number—1 moist, 2 dry, 3 dry, average moist; 4 dry, 5 moist, 6 moist, average moist.

[23] Pressure was raised to 2.8 kg. per sq. cm.

TABLE 18.—Permeability of Mortars Containing Inert Fillers

1 Part Portland Cement to 4 Parts Sand

[All of the materials were dried and ground to pass a 200-mesh sieve before adding to the mortars. Assuming the weight of cement at 100 pounds per cubic foot (1.60 grams per cubic centimeter), 20 per cent by volume of each of the materials was added to the mixture.]

No. of compound	Test piece No.	Age, 26 weeks [24]			Age, 52 weeks		
		Pressure in kilograms	Hours under pressure	Flow in cubic centimeters	Pressure in kilograms	Hours under pressure	Flow in cubic centimeters
45 (sand)	1	5.6	24	0	5.6	96	m
	2	5.6	24	0	5.6	96	m
	3	5.6	24	m	5.6	96	0
Average				m			m
43 (Missouri clay)	1	5.6	24	0	5.6	96	m
	2	5.6	24	0	5.6	96	m
	3	5.6	24	0	5.6	96	0
Average				0			m
41 (New York clay)	1	5.6	24	0	5.6	72	0
	2	5.6	24	m	5.6	72	0
	3	5.6	24	0	5.6	72	0
Average				m			0
42 (fire clay)	1	5.6	24	m	5.6	72	0
	2	5.6	24	m	5.6	72	0
	3	5.6	24	0	5.6	72	0
Average				m			0
44 [25] (feldspar)	1	2.8	24	0	4.2	48	m
	2	2.8	24	0	4.2	48	m
	3	2.8	24	0	4.2	48	0
Average				0			m

[24] For the 4-week period all test pieces were tested under 1.4 kilograms pressure for 24 hours without flow or becoming "moist." Original records were lost in transit and details can not be given. For the 13-week period all original records were lost in transit, except for compound No. 44 (feldspar), which (at 2.8 kilograms pressure for 7 hours) shows moist for test piece No. 1, dry for No. 2, and moist for No. 3 and average.

[25] At 5.6 kilograms all three test pieces were cracked after 24 hours.

TABLE 19.—Damp-proof Qualities of Treated Mortars

1 Part Portland Cement to 4 Parts Sand

No. of compound	Amount incorporated and manner of incorporation	Behavior of 3 test pieces in ½ inch of water	Behavior of 3 test pieces in 1 inch of water	Remarks
0	No compound incorporated.	Sound after 34 days' exposure.	Sound after 108 days' exposure.	Placed in 1½ inches of water and failed in 58 days.
32	2% based on the weight of dry cement, or 2 gms. compound for 100 gms. cement. Mixed with dry cement before mixing with sand and water.	Sound after 24 days' exposure.	do	Placed in 1½ inches of water, 1 failed 66 days, 2 sound after 4 months 22 days' exposure.
31	do	Sound after 35 days' exposure.	Sound after 82 days' exposure.	Placed in 1½ inches of water for 6 months 18 days without failing.
33	do	Sound after 34 days' exposure.	do	Placed in 1½ inches of water for 6 months without failing.
30	do	Sound after 27 days' exposure.	Sound after 83 days' exposure.	Do.
29	do	Sound after 28 days' exposure.	do	Placed in 1½ inches of water for 6 months 6 days without failing.

TABLE 19.—Damp-proof Qualities of Treated Mortars—Continued

1 Part Portland Cement to 4 Parts Sand—Continued

No. of compound	Amount incorporated and manner of incorporation	Behavior of 3 test pieces in ½ inch of water	Behavior of 3 test pieces in 1 inch of water	Remarks
28.....	5% based on the weight of dry cement, or 5 gms. to 100 gms. of cement. Mixed with dry cement before mixing with sand and water.	Sound after 28 days' exposure,	Sound after 83 days' exposure,	Placed in 1½ inches of water for 6 months 6 days without failing.
27.....	2% based on the weight of dry cement, or 2 gms. of compound to 100 gms. cement. Mixed with dry cement before mixing with sand and water.	Two failed in 2 days and 1 in 19 days.	.....	On repeating test all 3 specimens failed in 1 day. (Test was repeated on the same 3 specimens)
27b.....	10% based on the weight of dry cement, or 10 gms. of compound to 100 gms. cement. Mixed with dry cement before mixing with sand and water.	Sound after 35 days' exposure.	Sound after 109 days' exposure.	Placed in 1½ inches of water for 6 months 7 days without failing.
37.....	This is a "waterproofed" cement, and it was substituted in place of all the Portland cement.	Sound after 28 days' exposure.	Sound after 83 days' exposure.	Placed in 1½ inches of water for 6 months 6 days without failing.
40.....	10% added to the mixing water; that is, 10 c c of compound to 100 c c of water. This mixture was made before adding water to sand and cement.	One failed in 19 days, another in 25 days. Third sound after 28 days.	Sound and remained sound after 83 days' exposure.	Sound and remained sound after 6 months 6 days' exposure in 1½ inches of water.
39.....	4.16% added to the mixing water; that is, 416 c c of compound to 10000 c c of water. This mixture was made before adding water to sand and cement.	Sound after 28 days' exposure.	Sound after 83 days' exposure.	Placed in 1½ inches of water for 6 months 6 days without failing.
38.....	5% based on the weight of dry cement, or 5 gms. of compound to 100 gms. of cement. Incorporated after mixing dry sand and cement together.	.....do.....	.....do.....	Placed in 1½ inches of water and failed in 2 days. Repeating this test they failed in 3 days.
34.....	2½% based on the weight of dry cement, or 25 gms. of compound to 1000 gms. of cement. Mixed with dry cement before mixing with sand and water.	Sound after 95 days' exposure.	Sound after 136 days' exposure.	
35.....	1% based on the weight of dry cement, or 1 gm. of compound to 100 gms of cement. Mixed with dry cement before mixing with sand and water.	Sound after 35 days' exposure.	Sound after 164 days' exposure.	
36.....	2% based on the weight of dry cement, or 2 gm. of compound to 100 gms. of cement. Mixed with dry cement before mixing with sand and water.	Sound after 125 days' exposure.	Sound after 64 days' exposure.	
23.....	This material was not incorporated in mortar but tested by itself. (See Analysis.) 12% water added.	Sound after 28 days' exposure.	Sound after 110 days' exposure.	

TABLE 19.—Damp-proof Qualities of Treated Mortars—Continued

1 Part Portland Cement to 6 Parts Sand

No. of compound	Behavior of 3 test pieces in ½ inch of water	Behavior of 3 test pieces in 1 inch of water	Remarks
0	Sound for 28 days' exposure	Sound for 7 days' exposure.	Placed in 1½ inches of water, 2 specimens failed in 6 days, and the third in 133 days.
32	Sound for 22 days' exposure	Sound for 108 days' exposure.	Placed in 1½ inches of water for 5 months 21 days without failing.
31	Two failed in 2 days, third in 2 days 4 hours.	.....	On repeating test all three specimens failed in 24 hours.
33	Sound for 34 days' exposure	Sound for 82 days' exposure.	Placed in 1½ inches of water; failed in 51 days.
30	Failed in 3 days	.....	On repeating test all three specimens failed in 24 hours.
29	Failed in 6 days	.....	
28	One failed in 8 days; two sound for 28 days' exposure.	Sound for 83 days' exposure.	Two sound specimens placed in 1½ inches of water. One failed in 29 days, other in 8 months 6 days.
27(a)	Failed in 2 days	.....	On repeating test all failed in 22 hours.
27(b)	Sound for 34 days' exposure	Sound for 108 days' exposure.	Placed in 1½ inches of water, 2 failed in 77 days, and one in 92 days.
37	Sound for 28 days' exposure	Sound for 83 days' exposure.	Placed in 1½ inches of water all 3 failed in 43 days.
40	One failed in 1 day, another in 1 day 3 hours, third in 2 days.	.....	On repeating test all failed in 1 day.
39	Sound for 28 days' exposure	Sound for 83 days' exposure.	Placed in 1½ inches of water one of the three specimens failed after 6 months 6 days' exposure.
38	Failed in 21 hours	.....	On repeating test all failed in 24 hours.
34	Failed in 24 days	.....	
35	Failed in 1 day and 8 hours	.....	
36	One failed in 38 days; two sound for 5 months 11 days' exposure.	Two sound for 64 days' exposure.	

1 Part Portland Cement to 8 Parts Sand

0	One failed in 4 hours, other 2 failed in 24 hours.	.....	On repeating test all failed in 4 hours.
32	Sound for 34 days' exposure	Sound for 82 days' exposure.	Placed in 1½ inches of water all failed in 4 months.
31	Two failed in 1 day; third specimen failed in 2 days.	.....	On repeating test all three failed in 6 hours.
3	One failed in 2 days, other 2 failed in 5 days.	.....	On repeating test two failed in 3 hours and one in 1 day (24 hours).
30	Two failed in 18 hours, other in 27 hours.	.....	On repeating test all failed in 1 day (24 hours).
29	Failed in 18 hours	.....	On repeating test all failed in 1 day.
28	Failed in 18 hours	.....	On repeating test all failed in 7 hours.
27(a)	One failed in 2 days, other two failed in 28 days.	.....	On repeating test one failed in 2 hours, one in 3 hours, and one in 4 hours.
27(b)	Failed in 3 days	.....	All failed in 4 hours on repeating test.
37	Sound for 28 days' exposure	Sound for 83 days' exposure.	Placed in 1½ inches of water all failed in 5 months 6 days.
40	Sound for 28 days' exposure	Sound for 83 days' exposure.	Placed in 1½ inches of water all failed in 3 days.
39	Sound for 28 days' exposure	Sound for 83 days' exposure.	Placed in 1½ inches of water all failed in 5 months and 6 days.
38	Failed in 21 hours	.....	On repeating test all failed in 3 hours.
34	Failed in 22 hours	.....	
35	Failed in 24 hours	.....	
36	Sound for 125 days' exposure.	Sound for 36 days' exposure.	

TABLE 20.—Absorption of Waterproofed Mortars

1 Part Typical Portland Cement to 4 Parts Sand

[Results are averages of 3 test pieces for each set.]

In damp room 4 weeks; immersed 4 weeks

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption											
			Previous to drying		Subsequent to drying									
					Immersed 30 minutes		Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
0	1, 2, 3	261.79	9.93	19.93	.....	.....	8.13	16.22	8.37	16.70	8.43	16.93	9.02	18.00
32	1, 2, 3	264.63	8.52	17.34	.....	.....	3.75	7.58	4.69	9.47	5.76	11.62	7.52	15.18
31	1. 2. 3	256.79	10.24	20.04	.....	.....	7.86	15.39	[1] 8.45	[1] 16.55	8.50	16.84	9.07	17.79
33	1, 2, 3	263.52	9.30	18.70	.....	.....	6.49	13.04	6.98	14.02	7.20	14.47	8.05	16.17
30	1, 2, 3	254.47	9.41	18.27	.....	.....	7.20	13.96	7.72	14.98	7.96	15.46	9.09	17.64
29	1, 2, 3	262.20	10.31	20.61	.....	.....	6.38	12.75	.....	.....	8.29	16.57	8.82	17.64
28	1, 2, 3	253.60	10.30	20.06	.....	.....	[2] 8.20	[2] 15.97	8.28	16.13	8.47	16.50	8.96	17.46
27a	1, 2, 3	255.93	9.79	19.53	.....	.....	[2] 7.79	[2] 15.20	8.01	15.62	8.50	16.79	9.32	18.19
27b	1, 2, 3	262.32	[3] 8.76	[3] 17.98	.....	.....	[2] 6.72	[2] 13.75	7.00	14.33	7.66	15.67	[4] 8.18	[4] 16.74
37	1, 2, 3	251.29	10.58	20.28	.....	.....	4.87	9.32	7.01	13.43	7.59	14.55	8.41	16.12
40	1, 2, 3	253.54	10.41	20.13	.....	.....	7.14	13.81	8.52	16.49	8.59	16.62	9.26	17.91
39	1, 2, 3	265.77	10.38	21.04	.....	.....	3.17	6.42	[1] 4.03	[1] 8.18	4.77	9.67	6.38	12.93
38	1, 2, 3	264.23	9.80	19.75	.....	.....	7.44	15.00	7.97	16.07	[5] 8.19	[5] 16.50	8.47	17.06
34	1, 2, 3	261.85	[6] 8.51	17.00	3.27	6.50	6.32	12.62	6.84	13.65	7.19	14.36	8.11	16.20
35	1, 2, 3	251.40	[6] 10.13	19.37	4.00	7.63	7.97	15.30	.....	.....	8.57	16.40	9.47	18.17
36	1, 2, 3	254.32	[6] 7.83	15.27	2.13	4.10	5.20	6.43	4.00	7.80	5.10	9.90	6.47	12.57

In damp room 13 weeks; immersed 1 week

0	4, 5, 6	261.01	7.63	15.30	.....	.....	7.37	14.70	[1] 7.60	[1] 15.17	[5] 7.70	[5] 15.37	[7] 8.33	[7] 16.57
32	4, 5, 6	263.05	8.57	17.27	.....	.....	4.00	8.13	5.30	10.67	5.73	11.50	6.47	13.00
31	4, 5, 6	260.52	7.40	14.70	.....	.....	[2] 7.23	[2] 14.37	.....	.....	7.57	15.07	8.10	16.10
33	4, 5, 6	262.08	6.70	13.43	.....	.....	5.90	11.80	6.53	13.07	6.83	13.70	7.57	15.17
30	4, 5, 6	255.81	7.33	15.30	.....	.....	7.63	15.00	8.00	15.63	8.13	16.00	9.07	17.73
29	4, 5, 6	253.01	8.53	16.57	.....	.....	7.83	15.23	8.27	16.00	8.70	16.90	9.70	18.53
28	4, 5, 6	252.52	8.50	17.10	.....	.....	8.43	16.23	8.73	16.80	9.00	17.37	9.83	18.93
27a	4, 5, 6	257.23	7.97	15.93	.....	.....	7.50	15.03	[1] 7.67	[1] 15.37	[5] 7.77	[5] 15.53	[7] 8.40	[7] 16.77
27b	4, 5, 6	265.75	9.63	19.53	.....	.....	8.07	16.33	8.37	17.00	8.67	17.50	.....	.....
37	4, 5, 6	251.19	6.93	13.20	.....	.....	6.50	12.47	7.10	13.57	7.63	14.60	8.67	15.60
40	4, 5, 6	251.94	8.73	16.73	.....	.....	8.57	16.53	8.73	16.93	8.97	17.10	9.60	18.47
39	4, 5, 6	259.13	7.40	14.57	.....	.....	3.20	6.30	3.99	7.67	4.53	9.00	5.87	11.57
38	4, 5, 6	259.00	7.73	15.30	.....	.....	7.10	14.10	7.83	15.00	8.10	16.10	8.53	16.90
34	4, 5, 6	260.46	8.83	17.57	3.07	6.13	6.50	12.90	7.10	14.07	7.47	14.83	8.37	16.53
35	4, 5, 6	252.72	9.53	18.40	3.23	6.23	7.30	14.00	7.57	14.68	7.63	14.70	9.27	17.80
36	4, 5, 6	255.01	8.57	16.73	.....	.....	.....	.....	[1] 5.65	[1] 10.95	6.33	12.30	[8] 7.57	14.67

NOTE.—Results indicated by the reference figures show the following variations in days immersed: [1] 4, [2] 2, [3] 25, [4] 19, [5] 8, [6] 7, [7] 29, [8] 30.

TABLE 20.—Absorption of Waterproofed Mortars—Continued

1 Part Typical Portland Cement to 4 Parts Sand—Continued

[Results are averages of 3 test pieces for each set.]

In damp room 26 weeks; immersed 1 week

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption											
			Previous to drying		Subsequent to drying									
					Immersed 30 minutes		Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
0	7, 8, 9	266.12	8.33	16.93	2.43	4.93	7.33	14.90	7.80	15.83	8.00	16.27	8.47	17.17
32	7, 8, 9	262.62	8.10	16.17	1.43	2.87	3.33	6.70	4.40	8.83	4.77	9.57	5.90	11.87
31	7, 8, 9	259.70	8.17	16.30	2.70	5.37	6.97	13.93	7.37	14.60	7.57	15.13	8.10	16.17
33	7, 8, 9	266.84	8.23	16.77	3.27	6.20	5.97	12.20	6.33	12.83	6.90	14.13	7.40	15.03
30	7, 8, 9	254.35	8.60	16.67	3.10	6.03	7.67	14.93	8.10	15.67	8.30	16.10	8.87	17.20
29	7, 8, 9	265.99	7.93	16.10	2.95	5.90	6.83	13.87	7.23	14.63	7.37	14.97	7.97	16.17
28	7, 8, 9	251.15	7.20	13.83	2.07	3.93	5.93	11.33	6.83	13.07	7.07	13.50	7.80	14.97
27a	7, 8, 9	259.79	7.80	15.43	2.27	4.50	5.37	10.63	7.00	13.83	7.37	14.67	8.03	15.93
27b	7, 8, 9													
37	7, 8, 9	251.18	8.60	16.47	2.07	3.90	4.47	8.57	5.43	10.53	5.90	11.30	6.70	12.80
40	7, 8, 9	255.23	9.63	18.67	4.50	8.73	7.90	15.43	8.17	15.80	8.27	16.00	8.93	17.30
39	7, 8, 9	263.70	10.70	21.50	1.03	2.07	2.03	4.13	3.03	6.00	3.80	7.63	5.87	11.77
38	7, 8, 9	266.50	8.17	16.60	1.50	3.10	5.63	11.53	7.00	14.23	7.20	14.70	7.83	15.97
34	7, 8, 9	261.82	8.77	17.53			6.23	12.50	7.20	14.40	7.40	14.77	7.87	15.73
35	7, 8, 9	255.10	7.47	14.50			7.17	14.00	7.53	14.73	7.93	15.40	8.80	17.13
36	7, 8, 9	258.70	6.17	12.17			2.67	5.23	3.53	6.97	4.33	8.57	5.47	10.80
23	7, 8, 9	287.38	6.80	14.90			3.17	6.93	4.30	9.40	4.60	10.10	5.23	11.43

In damp room 52 weeks; immersed 1 week

0	10, 11, 12	263.45	5.70	11.43			5.27	10.50	5.93	12.00	6.47	13.00	7.20	14.50
32	10, 11, 12	265.28	6.10	12.37			[3] 2.37	[3] 4.77	[1] 3.80	[1] 7.67	[5] 4.53	[5] 9.17	[7] 5.43	[7] 11.07
31	10, 11, 12	261.72	6.37	12.70			[2] 6.40	[2] 12.77	6.50	12.93	6.70	13.37	7.17	14.30
33	10, 11, 12	263.83	6.50	13.00			5.57	11.20	6.40	12.83	6.70	13.50	7.20	14.40
30	10, 11, 12	260.30	6.67	13.27			6.47	12.83	6.77	13.47	6.93	13.80	7.33	14.50
29	10, 11, 12	263.67	7.17	14.40			4.97	10.00	6.97	14.03			7.77	15.63
28	10, 11, 12	252.27	7.37	14.13			6.43	12.40	7.23	13.90			7.90	15.17
27a	10, 11, 12	265.92	7.33	14.83			6.80	13.83	7.40	15.07	7.63	15.50	7.97	16.17
27b	10, 11, 12	269.20	6.87	14.07			4.87	10.03	6.70	13.80	7.13	14.67	7.73	15.87
37	10, 11, 12	254.02	5.90	11.43			4.60	8.97	5.70	11.10			6.53	12.67
40	10, 11, 12	259.08	8.20	16.20			7.77	15.37	7.93	15.70	8.13	16.03	8.50	16.77
39	10, 11, 12	264.53	6.53	13.17			2.50	5.03	4.17	8.37	5.10	10.33	6.27	12.63
38	10, 11, 12	267.53	6.80	13.93			5.47	11.17	6.97	14.23	7 30	14.87	7.77	15.77
23	10, 11, 12	287.98	5.67	12.47			2.33	5.10	3.07	6.73	3.67	8.07	4.37	9.70

TABLE 21.—Absorption of Waterproofed Mortars

1 Part Typical Portland Cement to 6 Parts Sand

[Results are averages of 3 test pieces for each set.]

In damp room 4 weeks; immersed 4 weeks

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption											
			Previous to drying		Subsequent to drying									
					Immersed 30 minutes		Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
0	1, 2, 3	251.08	10.08	21.22	.....	.....	[1] 8.48	[1] 16.24	8.61	15.48	9.19	17.60	9.85	18.86
32	1, 2, 3	255.83	9.69	18.92	.....	.....	4.46	8.70	5.55	10.82	6.74	13.16	8.68	16.93
31	1, 2, 3	252.88	[2] 10.72	[2] 20.67	.....	.....	7.95	15.34	8.55	16.50	8.87	17.12	9.37	18.07
33	1, 2, 3	249.29	9.82	18.68	.....	.....	6.66	12.68	7.38	14.04	7.73	14.69	8.36	17.82
30	1, 2, 3	247.04	11.24	21.17	.....	.....	7.51	14.14	8.65	16.29	8.93	16.83	9.72	18.32
29	1, 2, 3	250.11	11.43	21.81	.....	.....	6.36	12.14	.....	.....	8.78	16.74	9.54	18.20
28	1, 2, 3	237.37	11.81	21.39	.....	.....	7.15	12.94	8.61	15.60	9.09	16.46	9.91	17.94
27a	1, 2, 3	252.48	11.63	22.41	.....	.....	8.65	16.66	9.38	18.06	9.69	18.65	10.18	19.62
27b	1, 2, 3	251.84	[2] 9.98	[2] 19.18	.....	.....	[1] 8.40	[1] 16.13	8.88	17.07	9.62	18.47	[3] 10.54	[3] 20.26
37	1, 2, 3	243.51	10.25	19.04	.....	.....	5.05	9.38	6.91	12.84	7.64	14.19	8.90	16.53
40	1, 2, 3	244.03	12.30	22.90	.....	.....	8.68	16.16	9.55	17.77	9.88	18.40	10.39	19.35
39	1, 2, 3	254.33	12.34	23.94	.....	.....	3.04	5.90	[1] 4.19	[1] 8.12	5.49	10.65	9.59	18.59
38	1, 2, 3	249.09	12.30	23.37	.....	.....	9.13	17.33	9.68	18.38	9.88	18.70	10.84	20.59
34	1, 2, 3	245.26	10.74	20.09	4.40	8.21	7.51	14.05	8.68	16.24	8.96	16.76	10.50	19.64
35	1, 2, 3	243.17	[4] 11.10	[4] 20.40	5.47	10.13	8.83	16.43	9.53	17.70	9.80	18.13	11.07	20.50
36	1, 2, 3	245.05	[4] 10.00	[4] 18.70	2.43	4.53	4.07	7.57	4.90	9.17	6.07	11.33	[5] 7.47	[5] 14.00

In damp room 13 weeks; immersed 1 week

0	4, 5, 6	246.29	8.47	15.91	.....	.....	8.10	15.21	[6] 8.34	[6] 15.67	8.46	15.88	9.18	17.23
32	4, 5, 6	256.24	[7] 10.07	[7] 19.74	.....	.....	4.49	8.76	[6] 5.85	[6] 11.43	[8] 6.35	[8] 12.41	7.48	14.63
31	4, 5, 6	246.76	8.53	16.03	.....	.....	[1] 8.13	[1] 15.33	.....	.....	8.73	16.40	9.40	17.70
33	4, 5, 6	252.28	7.21	13.88	.....	.....	6.09	11.72	7.01	13.51	7.40	14.24	8.51	16.37
30	4, 5, 6	244.89	7.91	14.78	.....	.....	7.53	14.63	8.27	15.45	8.63	16.11	9.72	18.16
29	4, 5, 6	247.35	9.13	17.23	.....	.....	8.40	15.84	8.83	16.65	9.37	17.67	10.39	19.61
28	4, 5, 6	240.55	9.06	16.63	.....	.....	8.48	15.56	8.79	16.14	9.25	16.98	10.34	18.98
27a	4, 5, 6	248.43	8.75	16.59	.....	.....	8.40	15.91	8.89	16.28	[8] 8.75	[8] 16.58	[9] 9.52	[9] 18.04
27b	4, 5, 6	254.97	9.30	18.47	.....	.....	7.78	15.14	8.13	15.82	8.42	16.37	.....	.....
37	4, 5, 6	237.80	6.95	12.61	.....	.....	6.34	12.59	7.60	13.79	8.26	14.99	9.76	17.71
40	4, 5, 6	247.28	10.32	19.05	.....	.....	9.28	17.15	9.51	17.57	9.83	18.15	10.61	19.69
39	4, 5, 6	249.02	8.14	15.50	.....	.....	3.30	6.28	4.15	7.89	4.80	9.12	6.37	12.09
38	4, 5, 6	249.13	9.28	17.62	.....	.....	8.64	16.40	9.12	17.33	9.50	18.05	10.24	19.45
34	4, 5, 6	248.21	11.08	20.98	3.17	5.99	6.95	13.15	7.83	14.82	8.45	16.00	9.61	18.20
35	4, 5, 6	244.05	11.07	20.61	4.28	7.99	8.62	16.05	8.95	16.73	9.05	16.85	9.50	17.68
36	4, 5, 6	244.28	11.47	21.37	.....	.....	.....	.....	[6] 7.09	[6] 13.20	7.57	14.10	[10] 8.63	[10] 16.02

NOTE.—Results indicated by the reference figures show the following variations in days immersed: [2] 20, [3] 25, [4] 7, [5] 21, [6] 4, [7] 28, [8] 8, [9] 29, [10] 30, [11] 6, [13] 31.

TABLE 21.—Absorption of Waterproofed Mortars—Continued

1 Part Typical Portland Cement to 6 Parts Sand—Continued

[Results are averages of 3 test pieces for each set.]

In damp room 26 weeks; immersed 1 week

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption											
			Previous to drying		Subsequent to drying									
					Immersed 30 minutes		Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
0	7, 8, 9	252.96	8.57	16.57	2.57	4.93	7.37	14.27	8.00	15.50	8.17	15.77	8.30	16.93
32	7, 8, 9	255.67	8.83	17.27	1.27	2.47	3.63	7.07	5.03	9.80	5.47	10.63	7.07	13.83
31	7, 8, 9	252.66	9.33	17.90	2.33	4.53	6.77	13.00	7.30	14.10	7.60	14.57	8.47	16.30
33	7, 8, 9	249.84	9.63	18.33	2.67	5.10	7.23	13.77	7.63	14.50	8.33	15.87	9.00	17.13
30	7, 8, 9	252.32	9.77	18.80	4.27	8.23	7.97	15.33	8.33	16.00	8.60	16.57	9.07	17.43
29	7, 8, 9	252.19	8.70	16.77	2.80	5.37	6.10	11.73	8.27	15.93	8.37	16.17	9.10	17.50
28	7, 8, 9	244.57	10.37	19.30	3.40	6.43	7.73	14.50	.....	.....	[11] 8.17	[11] 15.27	[12] 9.13	[12] 17.03
27a	7, 8, 9	251.12	6.90	13.27	2.83	5.43	6.47	12.40	6.77	12.97	7.37	14.10	8.47	16.17
27b	7, 8, 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
37	7, 8, 9	243.72	10.17	18.97	2.50	4.67	6.17	11.50	.....	.....	[11] 7.07	[11] 13.17	[12] 8.57	[12] 15.97
40	7, 8, 9	247.25	11.03	20.80	5.20	9.80	8.63	16.23	8.70	16.43	9.07	17.10	9.63	18.20
39	7, 8, 9	249.34	12.43	23.57	1.97	3.67	3.63	6.87	4.50	8.50	5.90	11.10	8.20	15.53
38	7, 8, 9	252.95	11.40	21.93	2.23	4.33	7.97	15.27	8.53	16.43	8.70	16.73	9.67	18.57
34	7, 8, 9	247.09	8.60	16.17	.....	.....	7.10	13.37	7.70	14.53	8.13	15.37	9.50	17.93
35	7, 8, 9	244.48	8.07	15.17	.....	.....	7.40	13.93	8.30	15.63	8.53	16.10	9.63	18.20
36	7, 8, 9	247.12	6.67	12.57	.....	.....	4.37	8.27	4.80	9.00	5.47	10.30	6.60	12.47
23	7, 8, 9	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

In damp room 52 weeks; immersed 1 week

0	10, 11, 12	251.28	7.03	13.47	.....	.....	6.70	12.87	7.03	13.57	7.43	14.30	7.97	15.23
32	10, 11, 12	257.98	7.13	14.03	.....	.....	[1] 2.77	[1] 5.40	[6] 4.93	[6] 9.73	5.80	11.40	6.97	13.77
31	10, 11, 12	252.88	7.63	14.70	.....	.....	6.90	13.30	7.40	14.23	8.13	15.63	8.40	16.27
33	10, 11, 12	255.38	5.53	10.80	.....	.....	3.17	6.20	5.50	10.70	5.90	10.57	6.73	13.10
30	10, 11, 12	247.72	7.70	14.57	.....	.....	7.43	14.07	7.80	14.77	8.07	15.17	8.50	16.07
29	10, 11, 12	255.27	8.13	15.80	.....	.....	7.00	13.57	8.20	15.90	.....	.....	8.83	17.20
28	10, 11, 12	245.68	7.07	13.23	.....	.....	6.20	11.60	6.80	12.80	.....	.....	7.98	14.90
27a	10, 11, 12	251.62	6.23	12.00	.....	.....	5.50	10.57	6.03	11.67	6.63	13.00	7.50	14.30
27b	10, 11, 12	259.51	7.27	14.43	.....	.....	5.83	11.67	[6] 6.57	[6] 13.07	7.03	13.87	8.20	16.23
37	10, 11, 12	247.30	6.90	13.07	.....	.....	6.53	12.23	6.93	13.07	7.30	13.77	7.70	14.53
40	10, 11, 12	247.93	8.63	16.30	.....	.....	8.10	15.27	8.20	15.53	8.50	16.03	8.97	16.90
39	10, 11, 12	254.07	5.80	11.23	.....	.....	2.67	5.10	4.23	8.23	5.23	10.10	6.63	12.83
38	10, 11, 12	254.78	7.50	14.53	.....	.....	5.23	10.13	7.27	14.10	7.77	15.13	8.27	16.13

TABLE 22.—Absorption of Waterproofed Mortars

1 Part Typical Portland Cement to 8 Parts Sand

[Results are averages of 3 test pieces for each set.]

In damp room 4 weeks; immersed 4 weeks

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption											
			Previous to drying		Subsequent to drying									
					Immersed 30 minutes		Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
0	1, 2, 3	241.25	11.21	20.63	.....	.....	[1] 9.06	[1] 16.67	9.14	16.81	9.78	18.00	10.84	19.95
32	1, 2, 3	251.40	9.89	18.97	.....	.....	5.41	10.37	[2] 5.77	[2] 11.07	6.48	12.42	8.09	15.51
31	1, 2, 3	247.24	[3] 11.21	[3] 21.15	.....	.....	[1] 8.61	[1] 16.24	8.80	16.60	9.34	17.61	10.12	19.09
33	1, 2, 3	242.51	12.21	21.58	.....	.....	8.33	15.41	9.39	17.37	10.43	19.31	12.00	22.19
30	1, 2, 3	241.88	12.11	22.34	.....	.....	8.42	15.54	9.08	16.75	9.42	17.38	10.48	19.33
29	1, 2, 3	244.12	11.41	21.24	.....	.....	[1] 8.82	[1] 16.43	8.85	16.48	9.34	17.40	10.20	19.00
28	1, 2, 3	236.08	11.92	21.46	.....	.....	7.42	13.35	8.55	15.40	8.93	16.08	9.70	17.47
27a	1, 2, 3	247.57	11.76	22.20	.....	.....	8.55	16.16	9.06	17.06	9.29	17.54	10.05	19.03
27b	1, 2, 3	250.34	[4] 10.92	[4] 20.89	.....	.....	[1] 8.60	[1] 16.46	8.93	16.90	9.37	17.92	[6] 9.94	[5] 19.03
37	1, 2, 3	241.21	11.28	20.75	.....	.....	8.04	11.12	8.06	14.83	8.36	15.75	9.53	17.53
40	1, 2, 3	243.60	12.56	23.34	.....	.....	9.34	17.36	[2] 9.70	[2] 18.02	9.84	18.28	10.50	19.52
39	1, 2, 3	245.37	12.38	23.17	.....	.....	[1] 6.28	[1] 11.74	6.62	12.39	7.83	14.64	10.03	18.83
38	1, 2, 3	249.76	11.63	22.16	.....	.....	7.03	13.48	[2] 8.93	[2] 17.02	9.23	17.57	10.06	19.17
34	1, 2, 3	248.84	[4] 10.60	[4] 19.47	4.77	8.73	7.44	13.67	8.53	15.67	8.86	16.27	11.04	20.29
35	1, 2, 3	239.80	[4] 10.73	[4] 19.67	8.13	14.90	9.23	16.90	9.50	17.37	9.90	18.10	11.60	21.23
36	1, 2, 3	241.34	[4] 11.00	[4] 20.23	2.23	4.20	3.97	7.23	4.67	8.63	6.10	11.20	8.50	15.87

In damp room 13 weeks; immersed 1 week

0	4, 5, 6	243.11	9.23	17.10	.....	.....	8.00	15.33	[2] 9.03	[3] 16.73	[8] 9.27	[8] 17.20	[7] 10.20	[7] 18.93
32	4, 5, 6	246.45	8.50	16.10	.....	.....	[1] 5.80	[1] 10.86	.....	.....	6.80	12.70	8.10	15.30
31	4, 5, 6	245.60	8.30	15.53	.....	.....	8.20	15.37	8.47	15.87	8.80	16.47	9.87	18.49
33	4, 5, 6	241.43	8.67	15.97	.....	.....	7.17	13.20	7.93	14.57	8.53	15.77	10.00	18.40
30	4, 5, 6	238.85	8.75	16.00	.....	.....	8.35	15.15	8.80	16.03	9.40	17.15	10.55	19.25
29	4, 5, 6	238.97	9.77	17.80	.....	.....	8.60	15.63	9.13	16.73	9.90	18.03	11.10	20.27
28	4, 5, 6	237.78	8.83	16.00	.....	.....	8.53	15.47	8.80	15.97	9.23	16.73	10.03	18.23
27a	4, 5, 6	246.45	[8] 11.63	[8] 21.87	.....	.....	9.30	16.57	9.23	17.43	9.43	17.80	.....	.....
27b	4, 5, 6	250.73	10.80	20.70	.....	.....	8.50	16.20	8.90	17.03	9.43	18.00	.....	.....
37	4, 5, 6	235.57	6.57	11.82	.....	.....	6.83	12.27	7.47	13.43	8.03	14.43	9.73	17.53
40	4, 5, 6	237.25	10.03	18.13	.....	.....	9.33	16.90	9.53	17.20	9.63	17.43	10.73	19.40
39	4, 5, 6	241.43	8.10	14.90	.....	.....	3.90	7.20	4.90	9.05	5.65	10.45	7.05	13.00
38	4, 5, 6	247.45	[8] 11.00	[8] 20.70	.....	.....	6.97	13.17	.....	.....	.....	.....	.....	.....
34	4, 5, 6	244.76	11.63	21.70	.....	.....	8.10	15.13	[2] 8.80	[3] 16.43	9.47	17.73	10.67	19.90
35	4, 5, 6	239.42	11.00	20.06	.....	.....	.....	.....	9.10	16.60	9.63	17.60	[9] 10.80	[9] 19.70
36	4, 5, 6	245.45	11.87	21.97	.....	.....	.....	.....	[2] 6.13	[3] 11.33	6.73	12.47	[9] 7.80	[9] 14.50

NOTE.—Results indicated by the reference figures show the following variations in days immersed: [1] 2, [2] 4, [3] 30, [4] 7, [5] 25, [6] 8, [7] 29, [8] 28, [9] 30.

TABLE 22.—Absorption of Waterproofed Mortars—Continued

1 Part Typical Portland Cement to 8 Parts Sand—Continued

In damp room 26 weeks; immersed 1 week

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption											
			Previous to drying		Subsequent to drying									
					Immersed 30 minutes		Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Volume	Volume	Weight	Volume
0	7, 8, 9	246.38	8.80	16.57	3.10	5.77	6.00	11.33	6.73	12.63	7.47	14.00	9.33	17.10
32	7, 8, 9	252.05	8.83	16.97	1.93	3.70	4.33	8.30	5.63	10.77	6.13	11.83	7.57	14.53
31	7, 8, 9	247.32	8.33	15.70	2.60	4.93	7.03	13.27	7.53	14.17	7.70	14.47	8.47	15.97
33	7, 8, 9	247.64	11.07	20.90	3.10	5.80	8.00	15.10	9.00	17.00	9.40	17.80	10.20	19.22
30	7, 8, 9	243.50	9.57	17.73	3.53	6.63	7.80	14.50	8.27	15.33	8.63	16.03	9.23	17.17
29	7, 8, 9	247.67	10.00	18.90	3.03	5.73	8.23	15.53	8.70	16.37	9.03	17.07	9.67	18.23
28	7, 8, 9	238.17	11.60	21.13	3.40	6.13	7.93	14.47	8.23	14.92	8.50	15.40	9.37	17.00
27a	7, 8, 9	246.81	9.93	18.73	2.83	5.30	8.07	15.17	8.37	15.77	8.67	16.37	9.47	17.80
37	7, 8, 9	240.91	10.43	19.13	2.83	5.23	6.53	12.07	7.20	13.30	7.80	14.33	9.10	16.77
40	7, 8, 9	239.67	10.73	19.57	3.67	6.67	7.70	14.07	7.83	14.33	8.27	15.07	8.93	16.37
39	7, 8, 9	244.96	13.10	24.43	1.23	2.27	2.20	4.17	3.27	6.07	5.00	9.33	8.33	15.57
38	7, 8, 9	252.07	11.47	22.03	2.90	5.53	7.57	14.50	8.27	15.90	8.40	16.17	9.73	18.73
34	7, 8, 9	242.64	8.37	15.47	.....	.....	7.03	13.03	7.73	14.33	8.17	15.07	9.57	17.73
35	7, 8, 9	240.65	8.83	16.23	.....	.....	8.73	16.03	9.13	16.77	9.80	18.00	10.60	19.43
36	7, 8, 9	244.63	6.37	11.87	.....	.....	4.77	8.93	5.10	9.57	5.90	11.00	7.17	13.43

In damp room 52 weeks; immersed 1 week

0	10, 11, 12	248.73	7.73	14.67	.....	.....	6.93	13.17	7.40	14.07	7.87	14.90	8.97	16.97
32	10, 11, 12	252.25	6.07	11.70	.....	.....	[1] 4.47	[1] 8.57	4.83	9.23	5.67	10.93	6.83	13.13
31	10, 11, 12	248.57	7.10	13.43	.....	.....	6.40	12.13	6.97	13.13	7.33	13.90	8.37	15.83
33	10, 11, 12	248.85	7.83	14.87	.....	.....	5.47	10.40	7.87	14.97	8.20	15.57	8.73	16.60
30	10, 11, 12	241.65	7.95	14.60	.....	.....	7.20	13.30	7.95	14.60	.....	.....	8.55	15.85
29	10, 11, 12	245.67	8.60	16.13	.....	.....	7.60	14.20	8.20	15.40	.....	.....	9.13	17.10
28	10, 11, 12	239.55	8.37	15.30	.....	.....	7.33	13.43	7.97	14.57	.....	.....	8.40	15.37
27a	10, 11, 12	249.28	8.97	17.00	.....	.....	8.39	15.93	8.70	16.57	8.97	17.07	9.47	18.03
27b	10, 11, 12	254.57	8.43	16.33	.....	.....	7.50	14.57	7.83	15.20	8.37	16.27	9.13	17.77
37	10, 11, 12	242.03	6.93	12.77	.....	.....	6.60	12.13	6.87	12.67	7.20	13.23	7.60	14.00
40	10, 11, 12	239.42	8.00	14.60	.....	.....	7.67	13.87	7.83	14.33	7.90	14.40	8.23	15.07
39	10, 11, 12	245.02	6.10	11.45	.....	.....	2.75	5.20	4.10	7.75	5.05	9.40	6.15	11.45
38	10, 11, 12	249.23	8.07	15.30	.....	.....	5.73	10.90	7.93	15.07	8.37	15.87	8.93	16.80

TABLE 23.—Absorption of Mortars Containing Inert Fillers

1 Part Typical Portland Cement to 4 Parts Sand

[Results are averages of 3 test pieces for each set.]

No. of compound	No. of test piece	Dry weight in grams	Percentage of absorption									
			Previous to drying		Subsequent to drying							
					Immersed 24 hours		Immersed 72 hours		Immersed 7 days		Immersed 28 days	
			Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
In damp room 13 weeks; immersed 1 week												
45	1, 2, 3	268.03	9.52	19.46	7.65	15.63	7.93	16.22	8.02	16.40	8.45	17.30
43	1, 2, 3	271.66	9.40	19.50	7.91	16.40	8.15	16.88	8.28	16.98	8.59	17.80
41	1, 2, 3	267.53	9.80	20.01	8.05	16.38	8.30	16.85	8.41	17.15	8.87	18.07
44	1, 2, 3	265.47	8.00	16.19	7.52	15.22	7.81	15.80	7.97	16.10	8.35	16.88
42	1, 2, 3	270.97	9.82	20.23	8.00	16.53	8.50	17.68	8.62	17.83	9.00	18.63
In damp room 26 weeks; immersed 1 week												
45	1, 2, 3	262.79	7.15	14.30	5.62	11.24	6.11	12.22	6.38	12.75	6.93	13.87
43	1, 2, 3	270.51	7.77	16.02	6.79	14.00	6.85	14.10	7.12	14.70	7.51	15.50
41	1, 2, 3	266.77	7.36	14.96	4.97	10.10	6.18	12.58	6.47	13.14	6.91	14.07
44	1, 2, 3	264.83	7.92	15.98	7.19	14.50	[36] 7.50	[36] 15.13	[37] 7.73	[37] 15.60	[38] 8.35	[38] 16.88
42	1, 2, 3	272.59	8.44	17.52	7.42	15.40	7.60	15.80	7.84	16.27	8.17	16.98
In damp room 52 weeks; immersed 1 week												
45	1, 2, 3	265 80	6.27	12.70	6.00	12.16	6.31	12.77	6.47	13.12	6.76	13.70
43	1, 2, 3	267.93	6.94	14.19	6.53	13.30	6.78	13.80	6.98	14.22	7.19	14.63
41	1, 2, 3	269.87	7.38	15.18	7.19	14.80	7.37	15.17	7.57	15.58	7.74	15.94
44	1, 2, 3	261.58	8.08	16.10	7.44	14.84	7.63	15.22	7.88	15.72	8.30	17.13
42	1, 2, 3	270.03	7.01	14.44	6.32	13.02	6.86	14.12	7.12	14.67	7.38	15.21

TABLE 24.—Tensile and Compressive Strength of Waterproofed Mortars

1 Part Portland Cement to 4 Parts Sand

Number of compound	Number of test pieces	Compressive strength (pounds per square inch)						Tensile strength (pounds per square inch)					
		Age in weeks when tested						Age in weeks when tested					
		1	2	4	13	26	52	1	2	4	13	26	52
0	1, 2, 3	750	1141	1493	2354	3158	3558	131	196	286	326	377	527
	Range [39]	72	49	173	97	250	450	5	28	62	6	39	76
32	1, 2, 3	1096	1357	2123	2908	3250	3850	154	229	295	345	409	475
	Range	86	289	84	250	1300	525	13	20	24	37	34	41
31	1, 2, 3	881	1335	1720	2274	2742	3569	172	204	256	311	370	418
	Range	185	107	85	282	975	438	21	36	43	65	38	65
35	1, 2, 3	993	1697	1837	2597	2933	3633	174	252	278	357	350	420
	Range	40	271	153	298	400	275	7	14	57	26	27	27
30	1, 2, 3	920	1244	1537	1794	2210	2642	156	215	254	302	334	420
	Range	90	231	97	272	330	525	18	27	47	26	54	72

[36] Immersed 96 hours. [37] Immersed 8 days. [38] Immersed 29 days.

[39] Range is the difference between maximum and minimum values for three test pieces.

TABLE 24.—Tensile and Compressive Strength of Waterproofed Mortars—Continued

1 Part Portland Cement to 4 Parts Sand—Continued

Number of compound	Number of test pieces	Compressive strength (pounds per square inch)						Tensile strength (pounds per square inch)					
		Age in weeks when tested						Age in weeks when tested					
		1	2	4	13	26	52	1	2	4	13	26	52
29	1, 2, 3	882	1324	1662	2069	2900	3567	206	246	312	347	405	492
	Range	43	137	76	452	100	500	49	4	25	13	23	21
28	1, 2, 3	1023	1211	1227	1727	2458	2883	185	227	235	309	375	322
	Range	190	406	161	140	75	400	6	20	47	37	36	86
27a	1, 2, 3	873	1472	1408	1868	2122	3025	153	211	238	295	320	429
	Range	60	362	70	198	229	175	14	18	61	89	37	19
27b	1, 2, 3	1292	1652	1934	3088	3142	3633	185	215	275	334	374	396
	Range	97	60	98	238	250	700	14	42	34	45	35	25
37	1, 2, 3	979	1409	1481	2244	2683	3967	226	234	266	358	385	507
	Range	85	52	154	105	925	350	24	21	27	36	16	30
40	1, 2, 3	1070	1130	1319	1725	2264	3267	174	193	241	300	318	469
	Range	22	58	81	319	237	500	10	13	20	34	4	22
39	1, 2, 3	823	1309	1328	1945	2342	3392	180	219	259	299	368	444
	Range	30	107	196	596	78	125	9	15	31	68	19	105
38	1, 2, 3	888	926	1907	2163	2758	3171	189	272	288	359	392	537
	Range	44	58	226	450	125	475	30	48	32	46	27	75
34	1, 2, 3	628	1320	1695	2244	2896	.....	124	209	289	353	427	.....
	Range	37	25	110	68	583	.....	34	12	36	74	89	.....
35	1, 2, 3	597	844	1226	1836	2151	.....	131	177	225	340	379	.....
	Range	3	106	33	114	126	.....	10	8	13	41	42	.....
36	1, 2, 3	1009	1115	1684	2190	2983	.....	176	226	289	346	551	.....
	Range	10	28	25	347	325	.....	42	24	21	18	83	.....
23	1, 2, 3	3325	3675	4417	5713	5867	7600	367	393	490	546	582	658
	Range	200	750	525	275	300	350	46	46	31	33	58	62

1 Part Portland Cement to 6 Parts Sand

0	1, 2, 3	559	612	733	1056	1326	1673	96	115	183	207	248	259
	Range	27	49	117	45	65	55	8	20	4	28	9	94
32	1, 2, 3	458	572	813	1126	1330	1950	80	129	164	200	243	275
	Range	52	53	148	109	68	150	4	15	22	38	8	16
31	1, 2, 3	511	516	748	1023	1253	1653	113	108	142	210	242	310
	Range	82	95	22	51	101	783	9	24	29	21	13	26
33	1, 2, 3	498	654	845	1498	1387	1796	112	148	197	211	263	265
	Range	21	14	125	78	28	12	9	43	10	33	21	24
30	1, 2, 3	467	597	646	1127	1314	1683	96	124	160	223	244	285
	Range	30	42	98	151	90	450	5	10	19	66	12	100
29	1, 2, 3	419	577	639	930	1277	1583	70	114	179	182	225	334
	Range	128	48	86	91	217	250	30	4	11	5	17	35
28	1, 2, 3	353	552	596	1021	1210	1775	78	113	140	187	229	287
	Range	33	97	67	99	285	138	29	15	16	25	14	60
27a	1, 2, 3	477	608	673	1026	1450	2108	92	122	148	206	225	311
	Range	24	87	52	25	110	275	6	9	21	28	16	35
27b	1, 2, 3	601	694	1051	1667	1714	2109	98	133	150	212	214	294
	Range	64	55	27	72	289	197	10	16	11	22	13	41
37	1, 2, 3	664	628	956	1132	1488	2092	148	148	163	218	239	321
	Range	74	147	349	135	38	250	10	37	25	19	18	40
40	1, 2, 3	521	624	735	1195	1100	1542	85	118	139	175	197	289
	Range	33	71	30	120	45	1100	11	15	21	9	18	52
39	1, 2, 3	323	474	567	826	1308	1892	78	105	146	187	202	339
	Range	25	2	57	62	626	575	5	6	8	11	93	78
38	1, 2, 3	498	621	764	1074	1172	1804	86	122	190	223	267	312
	Range	66	30	129	21	35	650	16	60	14	42	28	20
34	1, 2, 3	242	559	723	1240	1335	.....	77	115	159	229	275	.....
	Range	17	78	70	96	214	.....	5	20	20	18	16	.....
35	1, 2, 3	339	397	637	1009	1323	.....	91	133	141	246	275	.....
	Range	32	21	27	31	99	.....	7	5	3	38	30	.....
36	1, 2, 3	425	536	583	1141	1496	.....	91	132	166	244	317	.....
	Range	38	17	57	80	12	.....	8	7	13	27	35	.....

TABLE 24.—Tensile and Compressive Strength of Waterproofed Mortars—Continued

1 Part Portland Cement to 8 Parts Sand

Number of compound	Number of test pieces	Compressive strength (pounds per square inch)						Tensile strength (pounds per square inch)					
		Age in weeks when tested						Age in weeks when tested					
		1	2	4	13	26	52	1	2	4	13	26	52
0	1, 2, 3	207	578	564	741	1064	1084	61	71	90	128	148	247
	Range	14	45	39	46	26	138	7	6	16	7	12	63
32	1, 2, 3	245	543	589	626	752	1227	55	83	121	155	186	.....
	Range	20	22	50	20	218	83	8	11	5	23	27	.....
31	1, 2, 3	273	440	508	533	894	1947	80	88	117	160	194	268
	Range	15	11	80	57	8	245	11	7	30	32	16	44
33	1, 2, 3	260	330	425	634	854	972	67	78	104	153	193	199
	Range	42	16	77	83	36	108	10	1	8	26	16	44
30	1, 2, 3	246	359	553	561	708	1066	62	91	126	139	194	324
	Range	24	67	75	70	30	266	8	29	24	16	35	161
29	1, 2, 3	261	386	418	518	871	1329	63	83	139	168	129	281
	Range	53	29	70	81	46	517	9	5	13	16	6	10
28	1, 2, 3	216	368	442	508	806	879	54	70	88	144	170	207
	Range	16	25	95	35	83	37	1	6	10	27	16	72
27a	1, 2, 3	294	421	500	622	760	1642	63	86	115	148	172	328
	Range	42	20	38	10	21	125	8	12	4	31	10	11
27b	1, 2, 3	298	411	554	605	849	1288	62	79	112	153	168	237
	Range	13	78	52	83	77	240	11	11	18	7	12	41
37	1, 2, 3	311	490	647	749	1029	1650	71	90	129	155	186	281
	Range	47	26	44	44	123	325	3	40	18	23	21	8
40	1, 2, 3	227	339	441	713	938	975	69	78	106	128	145	200
	Range	40	30	53	33	30	100	0	5	11	15	20	55
39	1, 2, 3	190	155	317	597	792	917	43	63	82	131	167	216
	Range	66	23	26	223	94	100	6	1	11	50	74	26
38	1, 2, 3	217	295	376	651	685	887	59	104	150	141	174	235
	Range	14	40	61	40	40	100	1	53	33	20	13	10
34	1, 2, 3	118	280	397	543	929	.....	43	62	94	192	217	.....
	Range	8	25	34	31	107	.....	6	10	6	27	7	.....
35	1, 2, 3	201	310	436	565	925	.....	52	70	103	153	223	.....
	Range	7	24	13	69	50	.....	0	6	10	15	70	.....
36	1, 2, 3	251	349	410	716	908	.....	57	86	108	161	208	.....
	Range	35	20	20	22	105	.....	4	7	10	12	18	.....

TABLE 25.—Tensile and Compressive Strength of Mortars Containing Inert Fillers

1 Part Portland Cement to 4 Parts Sand

Number of compound	Number of test pieces	Compressive strength (pounds per square inch)						Tensile strength (pounds per square inch)					
		Age in weeks when tested						Age in weeks when tested					
		1	2	4	13	26	52	1	2	4	13	26	52
0	1, 2, 3	750	1141	1493	2354	3158	3733	131	196	286	326	377	527
	Range [40]	72	40	173	96	250	430	4	28	62	6	39	76
45	1, 2, 3	1140	1529	1674	3105	3750	4517	209	253	272	380	432	536
	Range	55	26	48	91	115	300	10	34	22	42	23	64
43	1, 2, 3	958	1383	1627	2244	3002	5175	196	253	278	370	436	473
	Range	244	103	62	122	300	475	16	29	25	13	10	178
41	1, 2, 3	1373	1253	1631	2435	3575	4450	191	226	240	375	408	475
	Range	142	91	260	142	400	550	9	13	57	63	51	11
42	1, 2, 3	1291	1500	1542	2195	2900	4593	197	232	224	309	360	470
	Range	186	29	41	95	125	600	29	12	14	24	29	25
44	1, 2, 3	525	930	1561	2528	2968	3417	152	200	266	299	422	460
	Range	13	42	108	200	404	350	7	27	30	21	27	65

[40] Range is the difference between maximum and minimum values for three test pieces.

DEPARTMENT OF COMMERCE AND LABOR

TECHNOLOGIC PAPERS

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S. W. STRATTON, DIRECTOR

No. 4

THE EFFECT OF ADDED FATTY AND OTHER OILS UPON THE CARBONIZATION OF MINERAL LUBRICATING OILS

BY

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Bureau of Standards

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THE EFFECT OF ADDED FATTY AND OTHER OILS UPON THE CARBONIZATION OF MINERAL LUBRICATING OILS

By C. E. Waters

In a paper on "The Behavior of High-Boiling Mineral Oils on Heating in the Air," [1] the author called attention to the fact that two straight mineral oils under investigation yielded more "carbonized" matter, insoluble in petroleum ether, when they were heated in brass tubes than when they were heated in glass tubes of the same dimensions. The reverse was true of a third oil having a saponification number indicating the presence of 0.5 per cent of fatty oil. This naturally suggested the advisability of determining the amount of carbonization of a straight mineral oil and of the same oil with known amounts of other constituents, such as lard oil, rosin oil, tallow, etc., added. The results of a series of such determinations are given in the present paper.

The oil selected was an engine oil flashing at 140° in the Pensky-Martens closed-cup apparatus. For the first tests there were seven samples, as follows:

No. 1.—The straight mineral oil. When 10 g, diluted with 50 cc of petroleum ether, was allowed to stand over night, it yielded only traces of precipitate. These proportions of oil and solvent are the same as those adopted in the carbonization tests.

No. 2.—The mineral oil heated with Ivory soap shavings for several hours in a closed flask on the steam bath. It was allowed to stand over night and then filtered. After standing several weeks in a closed bottle it set to a sort of jelly, but became perfectly fluid on shaking and remained so. Very little soap was in solution, for it gave only 0.03 per cent of ash.

No. 3.—The mineral oil saturated with rosin in the same way as with soap. It yielded only 0.03 per cent of matter insoluble in petroleum ether.

No. 4.—A 10 per cent solution of rosin oil in mineral oil.

[1] Bull., Bureau of Standards, 7, p. 365; 1911. J. Ind. Eng. Chem., 8, p. 233; 1911.

No. 5.—A 10 per cent solution of rapeseed oil in mineral oil.
No. 6.—A 10 per cent solution of lard oil in mineral oil.
No. 7.—A 5 per cent solution of tallow in mineral oil. It yielded 0.20 per cent of matter insoluble in petroleum ether.

As shown in the earlier paper, and confirmed by other determinations to be mentioned later, the insoluble precipitate is an oxidation product. It ought therefore to vary in amount with the time of heating and with the surface of oil exposed to the air. Hence it was first necessary to obtain a set of flasks as nearly alike as possible in internal diameter and in bore of neck. Erlenmeyer flasks of Jena glass were used, and by measuring all that were on hand with a pair of inside calipers made for the purpose, a sufficient number of almost exactly the same dimensions was obtained. Their inside diameter at the widest part was 65 mm, and the bore of the neck 21 mm. They were of 150 cc capacity.

For each determination approximately 10-gram samples were introduced into the flasks, which were then heated to 250° for 5 hours (instead of 3 hours as in our earlier work) in the air bath described in the former paper. The flasks, it may be remembered, were suspended by their necks from openings cut in the cover of the bath, and there was perfect freedom of diffusion of oil vapors and air. After cooling, the flasks were wiped off and weighed to determine the loss by volatilization. Then, after adding 50 cc of petroleum ether, corking and shaking the flasks with a gentle rotary motion until the thick residue went into solution as completely as possible, they were allowed to stand about 22 hours. This length of time seemed to be necessary for complete precipitation and agglomeration of the insoluble matter in a form admitting of easy filtration. If allowed to stand only about 16 hours it was far less manageable.

The insoluble matter was filtered off on Gooch crucibles prepared with a disk of "blue-ribbon" paper (cut with a cork borer), covered with a fairly thick felt of fine asbestos. The residue on the filter was washed with petroleum ether and dried at 93°–95° before weighing. Attempts to dry at the traditional 105°, in some of our earlier work, showed that there was danger of melting the precipitate. The flasks were, of course, thoroughly rinsed

with petroleum ether to remove all oil and precipitate. They were also heated to the same temperature and weighed in order to determine the amount of varnish-like coating on the walls.

During the dry, cold weather, when a large part of the work was done, it was found difficult to entirely avoid static electrical disturbances when weighing. But the errors so caused could not have amounted to more than 2 mg—a negligible quantity in weighing the flasks. The precaution was always taken to touch the balance pan with the finger two or three times in making the final adjustment of the rider.

In making the determinations, four flasks, usually with a different sample in each, were heated at one time. The set of twelve flasks was also used in regular rotation as far as possible. These precautions were taken in order to eliminate accidental variations caused by irregular heating, differences in the dimensions of the flasks, and possible catalytic effects due to the walls of the flasks, as suggested in the first paper.

It may appear to be unnecessary, but for the sake of completeness the flask numbers and the number of each heat are included among the data.

No. 1.—Straight Mineral Oil

Flask No. / Heat No.	1 / 1	8 / 2	3 / 4	10 / 6	5 / 8	12 / 9	3 / 11	6 / 13	Averages
Evaporation loss, per cent	61.5	47.8	36.8	34.0	34.9	39.5	45.1	51.0	.....
"Varnish," per cent	0.46	0.35	0.39	0.30	0.12	0.60	0.25	0.20	0.33
Insoluble, per cent	2.60	2.46	2.07	2.02	1.74	2.65	2.20	2.33	2.26
Total residue, per cent	3.06	2.81	2.46	2.32	1.86	3.25	2.45	2.53	2.59

No. 2.—Mineral Oil Containing Soap

Flask No. / Heat No.	2 / 1	9 / 3	4 / 4	11 / 6	6 / 8	5 / 10	4 / 11	7 / 13	Averages
Evaporation loss, per cent	37.1	45.0	49.8	50.9	45.9	42.1	52.8	48.8	.....
"Varnish," per cent	0.13	0.13	0.14	0.04	0.12	0.05	0.14	0.10	0.11
Insoluble, per cent	1.96	2.08	1.93	1.92	1.89	1.78	2.61	2.27	2.06
Total residue, per cent	2.09	2.21	2.07	1.96	2.01	1.83	2.75	2.37	2.17

No. 3.—Mineral Oil Containing Rosin

Flask No.	3	10	5	12	7	6	9	8	Averages
Heat No.	1	3	5	6	[1] 8	10	12	13	
Evaporation loss, per cent	47.1	49.2	40.0	35.1	32.9	51.0	60.2	38.4	.....
"Varnish," per cent	0.16	0.19	0.27	0.20	0.46	0.35	.....	0.28	0.27
Insoluble, per cent	2.22	2.18	1.96	1.83	2.34	2.72	2.51	2.25	2.25
Total residue, per cent	2.38	2.37	2.23	2.03	2.80	3.07	.....	2.53	2.52

No. 4.—Mineral Oil Containing Rosin Oil

Flask No.	4	11	6	1	8	7	10	1	Averages
Heat No.	1	3	5	7	[1] 8	10	12	14	
Evaporation loss, per cent	44.1	47.2	56.1	65.5	41.7	36.7	34.4	43.5	.....
"Varnish," per cent	0.34	0.16	0.14	0.40	0.20	0.18	.....	0.07	0.21
Insoluble, per cent	1.84	2.02	2.10	2.59	1.79	1.90	1.76	1.19	1.90
Total residue, per cent	2.18	2.18	2.24	2.99	1.99	2.08	.....	1.26	2.11

[1] In heat No. 8 there was some difficulty in regulating the temperature.

No. 5.—Mineral Oil Containing Rapeseed Oil

Flask No.	5	12	7	2	9	8	11	2	Averages
Heat No.	2	3	5	7	9	10	12	14	
Evaporation loss, per cent	36.4	50.1	48.6	44.6	34.4	43.2	45.1	26.8	.....
"Varnish," per cent	1.39	1.35	1.45	1.36	1.55	1.85	.....	0.67	1.37
Insoluble, per cent	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.02	0.01
Total residue, per cent	1.40	1.36	1.47	1.37	1.57	1.86	.....	0.69	1.38

The reason for the apparently low percentage of "insoluble" and the high percentage of "varnish" is that the flocculent precipitate at first thrown out of the heated oil by the petroleum ether collected, on standing, in small, hard lumps on the bottom of the flask and could not be washed out. No. 6, containing lard oil, showed a tendency in the same direction, but the residue was easily dislodged by a strong stream of petroleum ether from a wash bottle.

No. 6.—Mineral Oil Containing Lard Oil

Flask No.	6	1	8	3	10	1	12	3	Aver-
Heat No.	2	4	5	7	9	11	12	14	ages
Evaporation loss, per cent	42.0	51.6	52.2	49.2	43.6	49.0	45.2	33.9	.....
"Varnish," per cent	0.08	0.03	0.04	0.06	0.24	0.02	.....	0.13	0.09
Insoluble, per cent	0.31	0.31	0.33	0.61	0.46	0.32	0.55	0.28	0.40
Total residue, per cent	0.39	0.34	0.37	0.67	0.70	0.34	.....	0.46	0.49

No. 7.—Mineral Oil Containing Tallow

Flask No.	7	2	9	4	11	2	5	4	Aver-
Heat No.	2	4	6	7	9	11	13	14	ages
Evaporation loss, per cent	45.5	38.1	47.9	46.6	41.9	46.8	40.2	35.6	.....
"Varnish," per cent	0.10	0.06	0.07	0.05	0.12	0.13	0.09	0.29	0.11
Insoluble, per cent	1.35	1.27	1.38	1.47	1.43	1.49	1.25	1.31	1.37
Total residue, per cent	1.45	1.33	1.45	1.52	1.55	1.62	1.34	1.60	1.48

The percentages of "insoluble" here given are not corrected for the amount (0.20 per cent) thrown out by petroleum ether before the oil was heated.

A second sample of engine oil, purporting to be the same as No. 1, was obtained, since no more of the latter was available, and it seemed advisable to make some determinations on several mixtures not thought of at first. The descriptions of these new mixtures follow:

No. 8.—New sample of mineral oil.

No. 9.—Mineral oil, to every 10 g of which was added 0.25 g of Syrian asphalt dissolved in 25 cc of xylene. The solution was always added after the oil was weighed, and the solvent driven off by heating on the steam bath, at the same time blowing a gentle current of air into the flask. Before heating, petroleum ether threw out 1.35 per cent of insoluble.

No. 10.—Mineral oil, to every 10 g of which 0.01 g of sulphur dissolved in 1 cc of xylene was added. In this case the solvent was not driven off before heating.

No. 11.—A 10 per cent solution of 55° paraffin in mineral oil. This could be poured about as well as a heavy cylinder oil.

No. 12.—A 10 per cent solution of linseed oil in mineral oil.

No. 13.—Mineral oil and soap. To every 10 g of the oil there was added before heating 0.50 g of finely powdered Ivory soap, dried at 100°–105°.

No. 14.—Mineral oil oxidized by the combined action of air and sunlight, as described in an earlier paper.[3] The oil was placed in a crystallizing dish, in a layer about 1.5 cm deep, covered with a second dish and exposed outside a southern window from February 21 until March 23. Every day or two the oil was thoroughly stirred.

No. 15.—A mixture of the mineral oil with "Kahlbaum" ferric oxide. In each 10 g of the mixture there was 0.086 g of the oxide.

No. 16.—Mineral oil oxidized in flasks, but otherwise like No. 14. The oxidation was carried out in this way in order to determine the gain in weight. The average for four flasks, all of which gained nearly the same amount, was 0.92 per cent. This figure represents absorbed oxygen minus carbon dioxide and a little water. The contents of the four flasks were mixed before determining the carbonization. Nearly all of the insoluble oxidation product remained on the walls of the flasks.

The results obtained on heating these oils under the same conditions as for oils 1 to 8 are here given:

No. 8.—Second Sample of Mineral Oil

Flask No.	5	9	7	1(new)	11	1	Averages
Heat No.	1	2	4	8	9	12	
Evaporation loss, per cent	41.1	34.6	43.6	60.1	49.1	44.0	.....
"Varnish," per cent	0.22	0.66	0.16	0.49	0.31	0.37	0.35
Insoluble, per cent	2.08	2.73	1.98	3.18	2.50	2.58	2.51
Total residue, per cent	2.30	3.39	2.14	3.67	2.81	2.95	2.86

No. 9.—Mineral Oil Containing Asphalt

Flask No.	6	5	8	9	5	2	Averages
Heat No.	1	4	4	9	10	12	
Evaporation loss, per cent	46.1	31.0	38.3	37.9	30.6	34.4	.....
"Varnish," per cent	0.31	0.29	0.21	0.22	0.35	0.36	0.29
Insoluble, per cent	4.95	4.55	4.40	4.55	4.66	4.84	4.66
Total residue, per cent	5.26	4.84	4.61	4.77	5.01	5.20	4.95

The percentages of insoluble here given are not corrected for the amount thrown out of the oil when petroleum ether is added before heating. As mentioned above, this was 1.35 per cent. The percentages given are figured on the basis of 10 g of oil.

[3] Bull., Bureau of Standards, 7, p. 227; 1911. J. Ind. Eng. Chem., 2, p. 451; 1910.

No. 10.—Mineral Oil Containing Sulphur

Flask No. / Heat No.	7 / 1	6 / 4	12 / 5	10 / 9	5 / 10	3 / 12	Averages
Evaporation loss, per cent	36.4	65.2	36.0	33.4	37.0	34.7	.....
"Varnish," per cent	0.37	0.54	0.56	0.27	0.19	0.29	0.37
Insoluble, per cent	2.81	3.34	2.57	1.89	2.14	2.39	2.52
Total residue, per cent	3.18	3.88	3.13	2.16	2.33	2.68	2.89

No. 11.—Mineral Oil Containing Paraffin

Flask No. / Heat No.	8 / 1	4 / 3	5 / 7	7 / 10	1 / 11	Averages
Evaporation loss, per cent	39.9	42.0	40.8	39.0	39.0	.....
"Varnish," per cent	0.37	0.15	0.15	0.40	0.41	0.30
Insoluble, per cent	2.59	2.39	2.33	2.95	3.23	2.70
Total residue, per cent	2.96	2.54	2.48	3.35	3.64	3.00

No. 12.—Mineral Oil Containing Linseed Oil

Flask No. / Heat No.	1 / 3	2 / 3	6 / 7	8 / 10	2 / 11	Averages
Evaporation loss, per cent	50.5	33.0	48.6	36.0	48.1	.....
"Varnish," per cent	6.10	5.29	6.31	6.72	7.09	6.30
Insoluble, per cent	0.02	0.03	0.01	0.01	0.01	0.02
Total residue, per cent	6.12	5.32	6.32	6.73	7.10	6.32

The petroleum ether threw out a thick, tarry deposit that adhered to the bottom of the flask. This was necessarily counted in with the true "varnish."

No. 13.—Mineral Oil Containing Soap

The contents of the flasks formed, after heating, a nearly solid cake which could be broken up only with difficulty in petroleum ether. The residue was so fine-grained and gummy that it could not be filtered off.

No. 14.—Mineral Oil Oxidized in Crystallizing Dishes

Flask No. / Heat No.	9 / 5	10 / 5	7 / 7	4 / 8	3 / 11	Averages
Evaporation loss, per cent	47.7	44.6	42.1	51.6	44.9	.....
"Varnish," per cent	0.34	0.30	0.31	0.16	0.26	0.28
Insoluble, per cent	5.69	5.06	5.64	5.87	6.76	6.00
Total residue, per cent	6.03	5.36	5.95	6.03	7.01	6.28

No. 15.—Mineral Oil Containing Ferric Oxide

Flask No. / Heat No.	3 / 3	11 / 5	2 / 8	3 / 8	4 / 11	Averages
Evaporation loss, per cent	35.5	51.5	57.1	42.4	44.3	.....
"Varnish," per cent	1.11	0.57	1.59	0.80	1.23	1.02
Insoluble, per cent (corr. for Fe_2O_3)	7.30	4.91	6.58	5.05	8.66	6.50
Total residue, per cent	8.41	5.48	8.17	5.65	9.89	7.52

The "insoluble" was corrected for ferric oxide by washing out the Gooch crucible with benzene. With one exception, the weight of the residue was about 2 mg, or 0.02 per cent, greater than the amount of ferric oxide known to be in 10 g of the unheated oil-ferric oxide mixture. Hence the percentages of "insoluble" given above are somewhat too low. The exact amount of the discrepancy must be greater than 0.02 per cent, however, for a small part of the oxide remained in the ring of "varnish" adhering to the walls of the flasks. There were, besides, traces that could not be removed from the bottoms of flasks even with the most careful washing with petroleum ether.

No. 16.—Mineral Oil Oxidized in Flasks

Flask No. / Heat No.	8 / 7	12 / 9	4 / 12	Averages.
Evaporation loss, per cent	42.9	40.8	56.0	.....
"Varnish," per cent	0.44	0.18	0.31	0.31
Insoluble, per cent	7.30	6.12	7.65	7.02
Total residue, per cent	7.74	6.30	7.96	7.33

In order to determine whether or not any "varnish" or insoluble is formed in the absence of air, 10-g samples of each of the oils numbered 5, 6, 7, and 8 were heated in flasks with the mouths covered with ground-glass plates. They were heated to 250° for 5 hours. In no case was there any "varnish" formed on the walls, and only traces of insoluble were thrown out by petroleum ether. The loss by evaporation represents in large part the oil which condensed on the glass plates and dripped off or was wiped off the necks of the flasks before they were weighed.

Sample	5	6	7	8
Evaporation loss, per cent	3.56	5.42	4.64	3.30

DISCUSSION OF RESULTS

In considering the percentages of insoluble obtained on heating any given sample of oil, it is evident that there are causes of variation that may or may not be capable of elimination. A frequent source of annoyance was the sudden changes in the temperature of the air bath. In all of this work two thermometers which gave almost identical readings when heated with their bulbs side by side in an oil bath, were used on opposite sides of the air bath with their bulbs on a level with the oil in the flasks. They were only 8 cm apart, yet would often vary 10° in their readings. Frequently they would be not more than a degree apart for an hour or more, and then one or both would show a change in temperature; or first one and then the other would show a higher reading. The copper bath, with a double bottom and sheathed on the sides with two layers of asbestos with a 3-mm air space between, was heated by a burner with a "rose" top giving a uniformly spreading flame. The flasks were only about a centimeter apart at their widest part and the thermometer bulbs were between opposite pairs of flasks. It seemed, therefore, as if the reactions of cracking and oxidation, which are endothermic and exothermic, respectively, might have something to do with the sudden variations. Evidence of cracking was frequently seen in the sudden evolution of dense fumes from one of the flasks while those next to it were in a comparatively quiescent state. Rarely the fumes ignited spontaneously.

It is also possible that air currents might have caused more or less of the products of combustion from the burner, and hence varying amounts of oxygen, to encircle the necks of the flasks on one side of the bath and thus lower or raise the percentages of insoluble formed. It is hoped to eliminate this possible source of variation and also the irregular heating by means of an electrically heated bath now being made.

The results given in the present paper show, as did those published before, that there is no apparent connection between the amounts of insoluble, evaporation and "varnish."

As to catalytic action, influencing the amount of insoluble, which was hinted at in the earlier paper, a tabulation of the present results fails to give any certain evidence of it.

In the following table are brought together the average values for "varnish," insoluble and total residue for each of the mixtures. There are also given the averages calculated after striking out the most widely variant values, with the exception of those for No. 15, all of which differed so much among themselves that such a recalculation would mean nothing.

TABLE SHOWING AVERAGE RESULTS

Sample	Contains	All values included			Aberrant values omitted		
		"Varnish"	Insoluble	Total residue	"Varnish"	Insoluble	Total residue
1	Mineral oil	0.33	2.26	2.59	0.32	2.21	2.53
2	Soap	0.11	2.06	2.17	0.13	1.93	2.06
3	Rosin	0.27	2.25	2.52	0.24	2.30	2.54
4	Rosin oil	0.21	1.90	2.11	0.17	1.90	2.07
5	Rapeseed oil	1.37	0.01	1.38	1.42	0.01	1.43
6	Lard oil	0.09	0.40	0.49	0.05	0.31	0.36
7	Tallow	0.11	1.37	1.48	0.09	1.37	1.46
8	Mineral oil (2)	0.35	2.51	2.86	0.35	2.60	2.95
9	Asphalt	0.29	4.66	4.95	0.29	4.66	4.95
10	Sulphur	0.37	2.52	2.89	0.31	2.59	2.90
11	Paraffin	0.30	2.70	3.00	0.39	2.44	2.83
12	Linseed oil	6.30	0.02	6.32	6.38	0.02	6.40
14	Oxidized mineral oil	0.28	6.00	6.28	0.30	5.82	6.12
15	Fe_2O_3	1.02	6.50	7.52			
16	Oxidized mineral oil	0.31	7.02	7.33	0.31	7.32	7.63

Comparing the results of Nos. 1 to 7, it is evident that, with the exception of adding rosin, the admixture of other oils to the mineral oil has caused a greater or less diminution in the amount of insoluble and total residue. The same is also true of the "varnish," for as already explained, the apparently high values obtained for No. 5 were caused by the adherence of the insoluble precipitate to the bottom of the flask.

Considering Nos. 8 to 16, we see that the addition of asphalt increases the percentage of insoluble. This is true even if we correct the figures given in the table by the amount precipitated by petroleum ether before the mixture is heated. This is equivalent to 1.35 per cent, calculated on the basis of 10 g of oil.

The addition of sulphur, contrary to expectation, caused no marked difference. The same is true of the addition of paraffin. Linseed oil, as was to be expected, enormously increased the amount of total residue.

The oil which was exposed to the action of sunlight and air in flasks (No. 16) was, presumably, more completely oxidized than that in the crystallizing dish, for it was in a thinner layer, and besides, the flasks were rotated each day so as to spread the oil on the walls. It is not surprising that the figures obtained on heating this oil are higher than those for No. 14.

The results obtained with the mixture containing ferric oxide are interesting, especially in connection with the statement of Worrall and Southcombe,[4] that the horny or granular deposit at times found in steam cylinders is Fe_2O_3 or Fe_3O_4 cemented together by oil. One would not expect to find much if any rusting inside of the cylinder or carbureter of a gas engine, but it is not impossible that the fine metallic powder resulting from the wearing of the piston and the cylinder walls may become oxidized and then further the carbonization of the lubricant.

CONCLUSIONS

It has been shown that the addition of various oils and other substances to a straight mineral oil affects the amount of carboni-

[4] J. Soc. Chem. Ind., 19, p. 525; 1900.

zation, as measured by the percentage of precipitate thrown out by petroleum ether, in various ways. Lubricants containing soap in quantity (see No. 13), rosin and asphalt, or which have been exposed to the action of sunlight and air, are to be avoided.

One must not conclude, however, from the low results obtained with mixtures containing tallow, lard oil, etc., that the addition of these oils is to be recommended. The presence of the fatty acids resulting from the decomposition of the oils may greatly increase the corrosion of the cylinder and in actual practice cause as much carbonization as the direct addition of ferric oxide would do.

It is intended in the near future to make a series of determinations by heating the above mixtures, and possibly others, with polished strips of iron, brass and other metals.

WASHINGTON, August 24, 1911.

DEPARTMENT OF COMMERCE AND LABOR

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 5

THE EFFECT OF HIGH-PRESSURE STEAM ON THE CRUSHING STRENGTH OF PORTLAND CEMENT MORTAR AND CONCRETE

BY

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Bureau of Standards

[SEPTEMBER 5, 1911]

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PREFACE.

The investigation herein reported was made in the Technologic Branch of the United States Geological Survey at the Structural Materials Testing Laboratories, St. Louis, Mo., of which Richard L. Humphrey was Engineer-in-charge. The work of these laboratories was transferred to the Bureau of Standards July 1, 1910. The present paper, written since that time, was prepared from the uncollated data then transferred.

THE EFFECT OF HIGH-PRESSURE STEAM ON THE CRUSHING STRENGTH OF PORTLAND CEMENT MORTAR AND CONCRETE

By Rudolph J. Wig

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1. INTRODUCTION

It is a well-known fact that the hardening of Portland cement is accelerated by exposure to heat after hydration, but the value of this acceleration and the possibilities of its application to commercial purposes have not been extensively investigated.

In the manufacture of cement products, such as building blocks, architectural stone, drain tile, sewer tile, fence posts, etc., it is highly desirable to produce a material of uniform and known quality. Under present methods of manufacture the product is not of uniform quality. Even under laboratory conditions of manufacturing, storing, and curing a variation of 50 per cent in strength may be obtained between maximum and minimum values for similar concrete, mixed and molded under apparently the same conditions.

At the present time many manufacturing plants find it to be economical and highly desirable to cure their products by exposing them to heat in the form of steam at atmospheric pressure.

By this means it is found that the concrete becomes sufficiently hard in the course of several days to permit handling and shipment. The heat accelerates the setting and also aids in the production of a more uniform quality of material.

The purpose of the investigations reported in this paper was to determine what acceleration in hardening could be obtained by using steam under pressure, with corresponding higher temperatures.

The material used in these tests was supplied by the following companies: Iola Portland Cement Co., Iola, Kans.; Atlas Portland Cement Co., Hannibal, Mo.; Whitehall Portland Cement Co., Cementon, Pa.; Universal Portland Cement Co., Chicago, Ill.; Edison Portland Cement Co., New Village, N. J.; Omega Portland Cement Co., Mosherville, Mich.; Old Dominion Portland Cement Co., Fordwick, Va.; Lehigh Portland Cement Co., Mitchell, Ind.; St. Louis Portland Cement Co., St. Louis, Mo.; Union Sand and Material Co., St. Louis, Mo.

Acknowledgment is made to Robert F. Havlik for his assistance in designing the apparatus and outlining the program.

2. OUTLINE OF TESTS

There were two series of investigations: 1. To determine the effect of different steam pressures on the hardening of Portland cement mortars. 2. To determine the effect of duration of steam exposure on the hardening of Portland cement mortars.

Inasmuch as mortar mixtures are extensively used in the manufacture of cement products, and since it was thought they would give relatively similar results to those which would be obtained with concrete mixtures, one mortar mixture exclusively was tested. This mortar was composed of 1 part by volume of Portland cement to 4 parts by volume of well-graded sand. Two percentages of water were used in mixing, corresponding to those employed in molding cement products. One has been termed a damp consistency, the mixture containing only sufficient water to permit of molding a ball in the hands and holding between the thumb and finger. Water could not be drawn to the surface by troweling. The other, designated a "quaking" consistency, con-

tained all the water it would hold and permit of making a ball in the hands and holding between the thumb and finger. Water could easily be drawn to the surface by the pressure of a trowel.

Unfortunately the second series of tests was not made until eight months after the first series. The same cement was used in both series but it was stored in galvanized-iron cans during this period and became slightly lumpy. The large lumps were screened out by passing the cement through a quarter-inch mesh sieve, and an endeavor was made to crush the small lumps; but it would appear from the results that the tests were affected somewhat by this difference in the quality of the cement, due to its age and condition, and the results of the second series are not directly comparable with those of the first series. However, each series is complete in itself and gives the desired information.

A detailed outline of tests is given in the table following:

OUTLINE OF TESTS

One part Portland cement to four parts Meramec River sand

Series	Steam pressure (gage)	Time in steam	Test pieces tested at the following periods in days				Total[1]
			2	7	14	28	
	Pounds	*Hours*					
1. Quaking consistency	Atmos.	48	3	3	3	3	12
	2	24	3	3	3	[2] 3	12
	10	24	3	3	3	3	12
	20	24	3	3	3	[3] 3	12
	40	24	3	3	3	[4] 3	12
	80	24	6	6	[5] 6	[6] 6	24
2. Quaking consistency	80	3	3	3	3	3	12
	80	12	3	3	3	3	12
	80	17	3	3	3	3	12
	80	24	3	[2] 3	3	3	12
	80	48	.....	3	3	3	9
2. Damp consistency	80	3	3	3	3	3	12
	80	6	3	3	3	3	12
	80	12	3	3	3	3	12
	80	24	3	3	3	3	12
	80	48	.....	3	3	3	9

[1] The total number of test pieces tested in the series here shown aggregate 198. [2] Tested when 113 days old. [3] One tested at 110 days, two at 297 days. [4] Two tested at 84 days, one at 110 days. [5] Three tested at 89 days. [6] Three tested at 77 days, one tested at 210, other two not tested.

3. TESTS OF CONSTITUENT MATERIALS

Only one sand, Meramec River sand, from Moselle, Mo., was used in these investigations. It is composed of flint grains having comparatively smooth surfaces. The yellowish-brown color of the flint imparts a tint of the same color to the sand as a whole. The physical properties and mechanical analysis of the sand are as follows:

Specific gravity	2.60
Percentage of voids (computed)	37.90
Weight (pounds per cubic foot)	100.6
Mechanical analysis:	
Sieve—	Per cent passing
200	0.20
100	1.30
80	3.60
50	13.90
40	37.00
30	64.00
20	81.50
10	97.00
4	100.00

The cement used is known as typical Portland cement, being prepared by thoroughly mixing together a number of Portland cements. The average chemical analysis of the individual brands of cement used is as follows:

	Per cent
Silica	21.70
Alumina	8.53
Ferric oxide	2.23
Lime	62.00
Magnesia	1.74
Sulphuric anhydride	1.67
Water	.43
Ignition loss	.98
Undetermined	.94

The average of the physical tests of the individual brands of cement used is as follows:

Specific gravity	3.11
Water for normal consistency [per cent]	21.4
Residue on sieves [per cent]:	
100	5.1
200	21.0

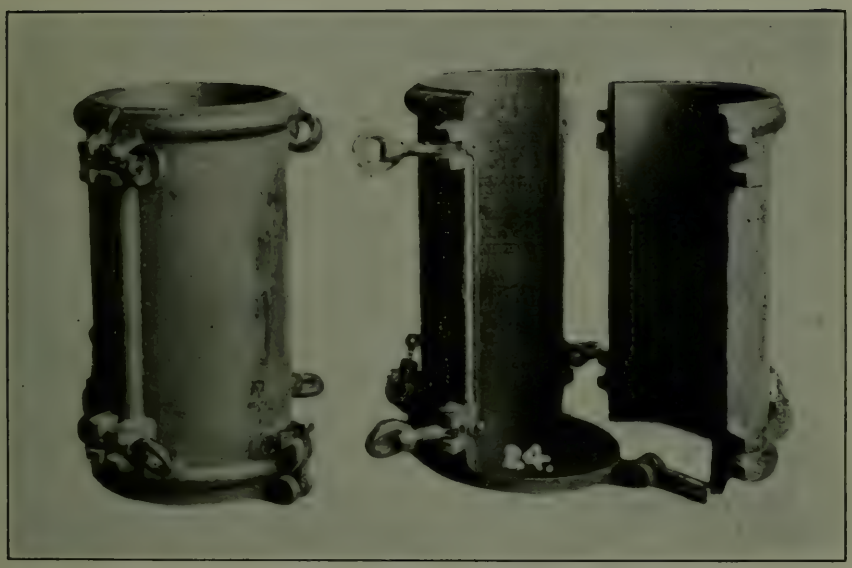

Fig. 1.—*Cast-Iron Cylinder Mold.*

Time of set:	
Vicat—	Minutes
Initial	135
Final	357
Gilmore—	
Initial	174
Final	402
Pats:	
Air at 70° F	All normal but two.
Water at 70° F	All normal.
Water at 212° F, 3 hours	All normal.
Steam at 212° F, 5 hours	All normal.

Detailed results of the chemical and physical tests of the cements used are given in Bulletin 344 of the United States Geological Survey, page 9.

4. DETAILS OF TESTS

Although the proportions of the mortar mixture are stated by volume measure, they were converted into their weight equivalents for greater accuracy in measuring the individual batches, an allowance being made for the moisture contained in the sand. The weight per cubic foot of the cement was assumed as 100 pounds and the weight per cubic foot of the dry sand was 100.6. This weight was determined under standard conditions as reported in Bulletin 329 of the United States Geological Survey. The moisture contained in the sand, as taken from the storage bin, was determined on a small sample each day. The weight of sand required for a batch was increased in amount equal to the percentage of moisture found to be present in the sand, and the quantity of water required to be added for the desired consistency was decreased in amount equal to that found to be present in the sand.

The materials were mixed in a cubical batch mixer. They were mixed dry for five minutes when the water was weighed, added, and materials mixed another five minutes.

The test piece was cylindrical in shape, 8 inches in diameter by 16 inches in length. The cast-iron mold in which these test pieces were formed is shown in Fig. 1. It is in three sections, held together by brass eye-screws and iron wedges. The inner surfaces are machined true.

The mold was filled one-fourth full and hand tamped systematically with a 13-pound peen-shaped tamper, care being taken to cover the entire surface. This operation was repeated until the mold was filled, when it was leveled off with a plasterer's trowel.

The molds were placed in the moist room immediately after filling, and the following day they were removed from the test pieces. After steam treatment all test pieces were stored in the moist room (with a few exceptions) until they were tested. The test pieces which were not steam treated were not removed from the moist

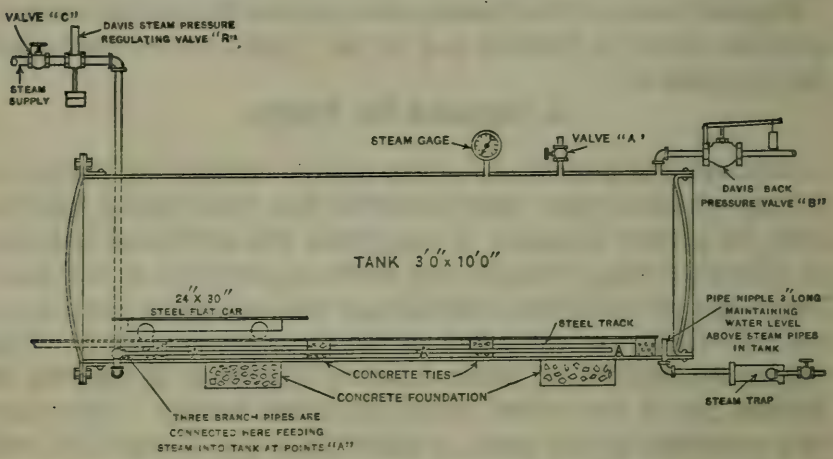
VALVE "C"
DAVIS STEAM PRESSURE REGULATING VALVE "R"
STEAM SUPPLY
STEAM GAGE
VALVE "A"
DAVIS BACK PRESSURE VALVE "B"
TANK 3'0" x 10'0"
24" X 30" STEEL FLAT CAR
STEEL TRACK
PIPE NIPPLE 2" LONG MAINTAINING WATER LEVEL ABOVE STEAM PIPES IN TANK
CONCRETE TIES
CONCRETE FOUNDATION
STEAM TRAP
THREE BRANCH PIPES ARE CONNECTED HERE FEEDING STEAM INTO TANK AT POINTS "A"

Fig. 4.—Diagram of Steam Curing Tank and Piping.

room until the day they were due to be tested. All test pieces in the moist room were sprinkled three times each 24 hours.

5. STEAM TREATMENT

The steam-curing equipment is shown in Figs. 2 and 3. The details of the construction and arrangement of the tank, piping, etc., are shown in Fig. 4. The equipment consisted of a curing tank 36 inches in diameter by 10 feet in length, with one head removable; three steel flat cars 24 inches wide by 30 inches long, track, steam-pressure regulating valve, steam trap, steam gage, and necessary piping. The steam was obtained from the power plant of the laboratory.

Fig. 2.—*View of Steam Curing Equipment.*

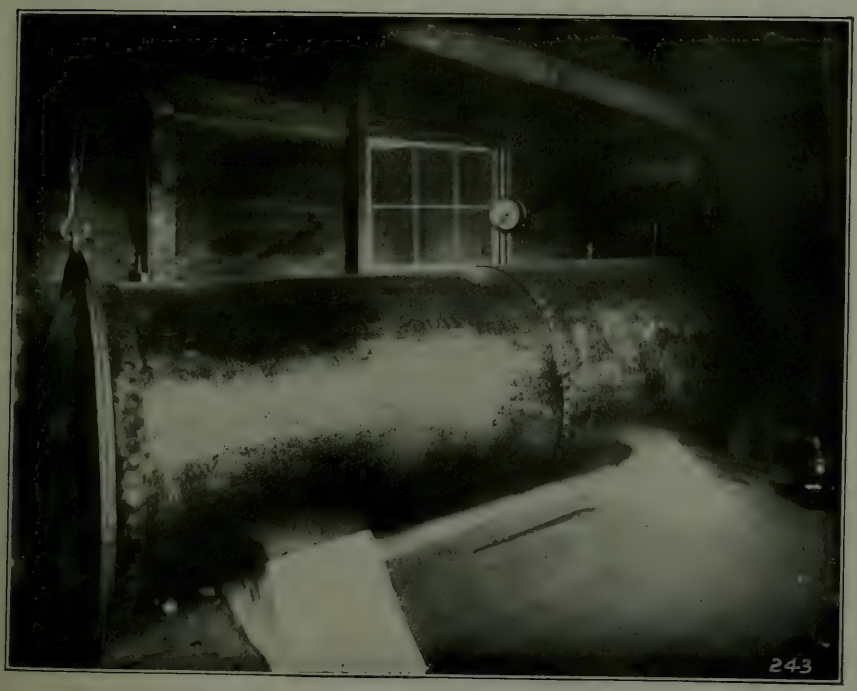

Fig. 3.—*Steam Curing Tank.*

The method of subjecting the test pieces to steam was as follows: Twenty-four hours after the test pieces were molded, the molds were removed and the test pieces were placed on the flat cars. The cars were rolled into the tank, the section of the track at the entrance of the tank was removed, and the head of the tank which was suspended on a rail was rolled into place and bolted. Valve *A* and the back pressure valve *B* were opened to permit the air to exhaust with the entrance of the steam. Valve *C* was opened, permitting the steam to flow through the pressure-regulating valve *R* into the tank. It required from 15 to 45 minutes to exhaust the air from the tank and bring the steam up to the desired pressure. For low pressures a mercury column was attached to the tank for greater accuracy in reading. The high pressures were read directly from the steam gage. When the desired pressure was reached the regulating valve *R* was set. After the desired period of steaming valve *C* was closed and valve *A*, back-pressure valve *B*, and the steam trap were opened, permitting the steam to exhaust from the tank. When the pressure was removed, the head of the tank was unbolted and removed. The cars were drawn from the tank, the test pieces removed, and either tested immediately for compressive strength or stored in the moist room until they were due to be tested.

6. COMPRESSION TESTS

The ends of the cylindrical test pieces were smoothed off with plaster of Paris at right angles to the axis a short time before testing. The method of applying this plaster cap was as follows:

The glass-top table used for this purpose was oiled, plaster of Paris was spread on it about one-fourth inch thick, and into this the cylinder was forced so that all but a layer about one-sixteenth inch thick was squeezed out. The sides of the cylinder were kept vertical by means of a spirit level. After the plaster was set, the test piece was removed from the glass and the other end was treated in the same way, both ends being made parallel, and perpendicular to the axis.

The test piece was placed in the testing machine without further bedding. The load was applied continuously at a speed of about

one-fortieth inch per minute until failure. The gross deformation readings were taken on one test piece from each set of three similar test pieces, readings being taken at 5000-pound intervals or about 100 pounds per square inch. The ultimate breaking load and the appearance of the ruptured cylinder were recorded. The capacity of the largest testing machine available at the time some of the earlier tests were made was 200 000 pounds, which was not suffi-

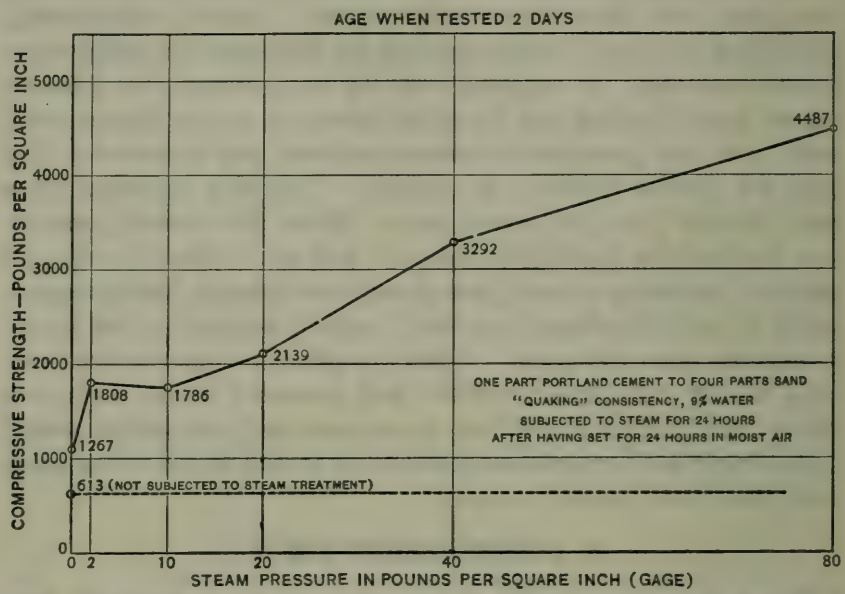

Fig. 5.—The Effect of Various Steam Pressures on the Compressive Strength of Portland Cement Mortar.

cient to cause the failure of all of the test pieces. A machine of 600 000 pounds capacity was available later, however, upon which all test pieces could be crushed to failure.

7. RESULTS OF TESTS

All test pieces were calipered and weighed previous to testing. The weight per cubic foot of the concrete or mortar was computed by dividing the weight by the volume computed from actual measurements of each test piece. The ultimate strength in pounds per square inch was obtained by dividing the total

breaking load by the sectional area computed from the actual measured diameter.

The individual results are recorded in the accompanying tables. The average results are shown diagrammatically in Figs. 5 to 9, inclusive. Each point on the curve is the average value of three test pieces unless otherwise stated.

Examining Figs. 5 and 6, in which the pressure and temperature, respectively, have been plotted with the ultimate compressive

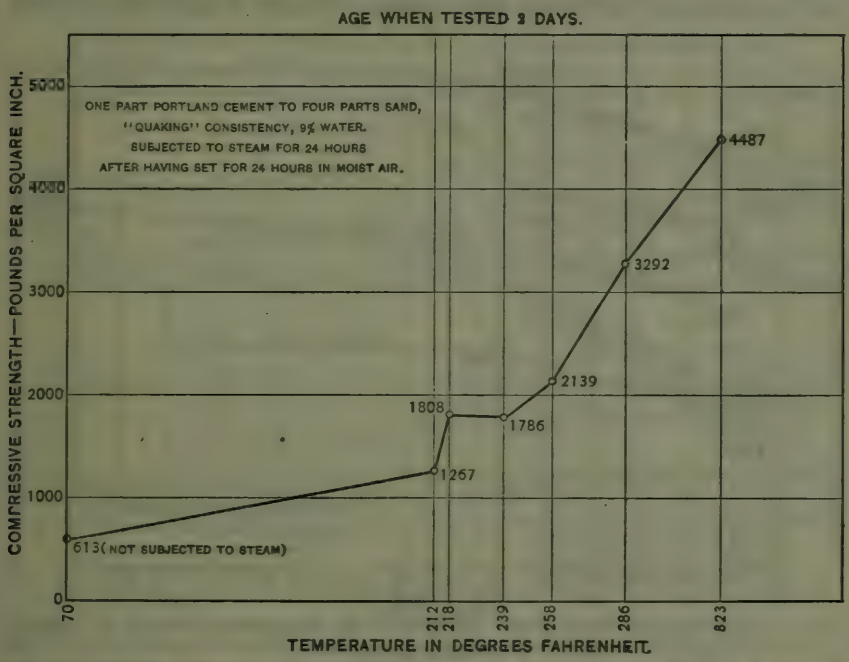

Fig. 6.—The Effect of Steam of Various Temperatures on the Compressive Strength of Portland Cement Mortar.

strength, it is observed that the acceleration in strength is very marked with the increase in the steam pressure and temperature. The gain in strength of the mortar exposed for 24 hours to steam at 80 pounds per square inch over the untreated mortar is 632 per cent. Lower steam pressures give a corresponding increase in strength over the untreated mortar, and from the slope of the curves it would appear that the increase in strength would be correspondingly higher for higher steam pressures and temperatures.

In Fig. 7 the age of the mortar when tested is plotted with the ultimate compressive strength for various steam pressures. It will be observed that there is no retrogression in strength with age in any case. The untreated mortar does not equal in strength the steam-cured mortar at any period, and at the age of 180 days it has less than 50 per cent of the strength of the mortar steam cured under 80 pounds pressure for 24 hours.

Fig. 8 shows how the length of time of exposure to steam affects the compressive strength, the steam pressure being maintained

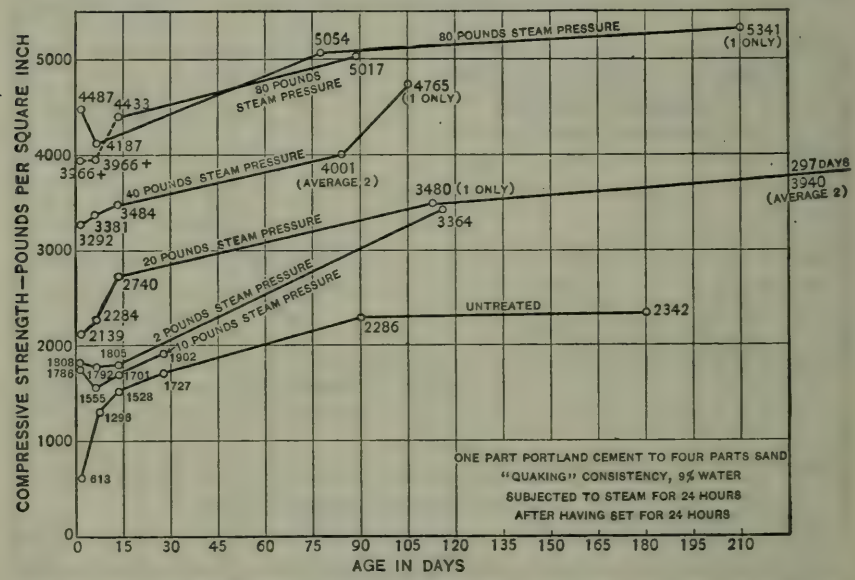

Fig. 7.—The Effect of Various Steam Pressures on the Compressive Strength of Portland Cement Mortar.

constant. All mortar exposed to steam under 80 pounds pressure for from 12 to 48 hours resulted in an increase in compressive strength over the untreated mortar. The increase in strength is from approximately 400 per cent at the age of two days to 100 per cent at the age of 28 days. None of the steam-cured mortar showed retrogression in strength between 2 and 28 days. The steam treatment of only three hours duration apparently had an injurious effect upon the hardening of the mortar, as that mortar developed only 60 per cent of the strength of the untreated mortar

at the age of 28 days. Comparing the 24-hour curve of Fig. 8 with the 24-hour curve of Fig. 7, it will be observed that the former lies below the latter for all periods, though, if the mortar were of the same quality in both cases, they should have developed equal strength. As previously explained, eight months elapsed between the making of the test pieces of these two series, and the cement had become slightly lumpy during this interval.

The mortar of series shown in Fig. 9 was mixed very dry, only

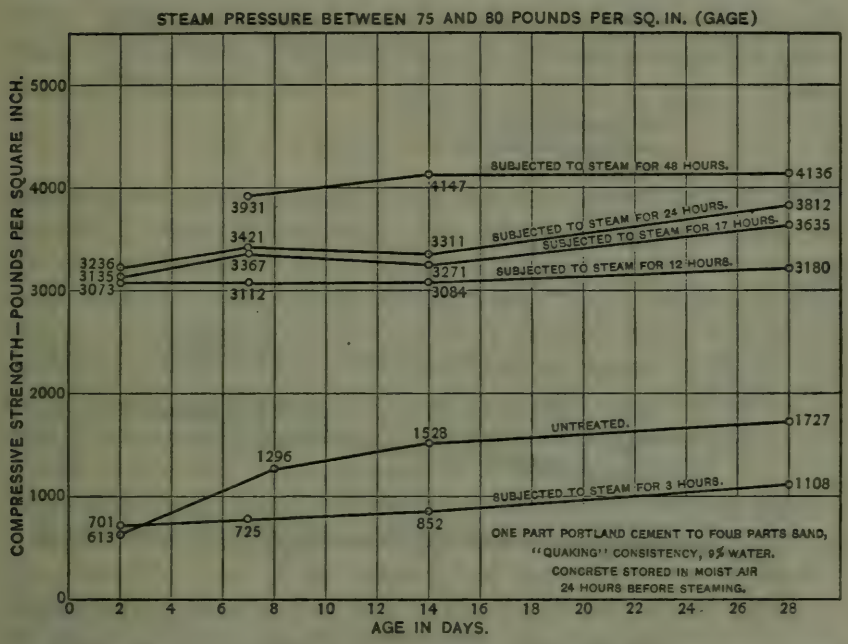

Fig. 8.—The Effect of Duration of Exposure to Steam on the Compressive Strength of Portland Cement Mortar.

5½ per cent of water being used, as compared with 9 per cent in mortar of quaking consistency. The untreated mortar of this series is approximately equal in strength to the untreated mortar of quaking consistency shown in Fig. 8, but the steam-cured mortar of the damp consistency has developed only about 50 per cent of the strength of the steam-cured mortar of the quaking consistency shown in Fig. 8. There is no apparent reason why the test pieces subjected to 12 hours steam treatment should exceed the strength

of those exposed to steam for 24 hours and 48 hours. The strength of very dry mixtures is more dependent upon the personal equation of molding than is the strength of wetter mixtures, and it may be that this lot of test pieces received more tamping, as it will be observed in the table that the weight per cubic foot of these test pieces was slightly greater than those of 24 and 48 hour tests.

Considering all of the above tests, it is apparent that steam under pressure will greatly accelerate the hardening. In order to

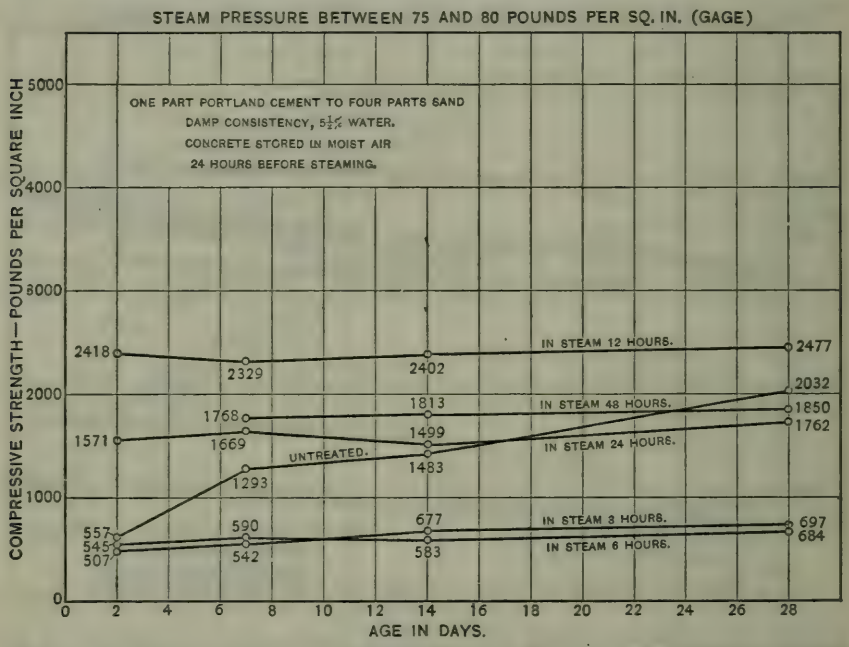

Fig. 9.—The Effect of Duration of Exposure to Steam on the Compressive Strength of Portland Cement Mortar.

determine the effect of steam on a lean mixture, one set of cylinders was molded of one part Portland cement and eight parts of sand, using 12½ per cent of water. They were permitted to obtain an initial set in moist air for 24 hours, when they were exposed to steam under 80 pounds pressure for 24 hours. They were tested immediately after removing from the steam, being two days old, with the following ultimate strength in compression (lbs. per sq. in.):

2038; 2307; 2040: Average, 2128.

From these tests it would appear that the strength of a steam-cured mortar is directly proportional to the cement content, but of course too much dependence should not be placed on a few results. One set of limestone concrete cylinders made in the proportion of one part of Portland cement, three parts sand, and six parts limestone was made and tested. They were placed in moist air for the first 24 hours, obtaining an initial set, after which they were exposed to steam at 80 pounds pressure for 24 hours. They were tested directly after taking from the steam, being two days old, with the following ultimate strength in compression (lbs. per sq. in.):

2429; 2615; 2320: Average, 2455.

Several sets of cylinders, both mortars and concretes, were exposed to steam immediately after molding without permitting the material to obtain an initial set. In every case the test pieces were cracked longitudinally by the steam, but the concrete or mortar was hard and the test pieces developed about half of the strength of those which were permitted to obtain an initial set before exposure to steam. It was found that if the concrete was mixed to a creamy consistency, although it was permitted to set in the air for four days previous to exposing to steam, the test pieces would be cracked longitudinally by the action of the steam

Several sets of cylinders were made in which hydrated lime was substituted for part of the cement, but the strength was reduced almost proportionally with the reduction in the cement content. the lime acting apparently as so much inert material.

SUMMARY.

The conclusions drawn on tests of this character must be understood as only directly applicable to materials similar to those tested and they must be limited by the limitations of the investigation. However, the test piece was of good size, and considering the large number made and tested, the reliability and accuracy of the results may be accepted.

1. Steam up to 80 pounds per square inch gage pressure has an accelerating action on the hardening of Portland cement mortar and concrete.

2. The compressive strength increases as the steam pressure is increased.

3. The compressive strength increases with the increase in the time of exposure to steam.

4. A compressive strength considerably (in some cases over 100 per cent) in excess of that obtained normally after aging for six months may be obtained in two days by using steam under pressure for curing the mortar.

5. Steam under pressure, if of sufficient duration, permanently accelerates the hardening of the mortar, giving subsequent constant increase in compressive strength with age.

6. The steam-cured mortar or concrete is of much more uniform appearance and much lighter in color than normally aged mortar or concrete made from the same materials.

7. The mortar or concrete should obtain an initial set before it is exposed to the steam treatment.

8. For steam curing a "quaking" or medium consistency is preferable to a very dry or a very wet consistency.

9. The initial modulus of elasticity and the yield point of the mortar increase directly with the duration of steam treatment.

10. The initial modulus of elasticity and the yield point of the mortar increase directly with the steam pressure.

11. The initial modulus of elasticity does not increase in direct proportion to the increase in the ultimate compressive strength of the steam-cured mortar.

12. Results indicate that the compressive strength obtained by steam curing is directly proportional to the cement content of the mortar.

WASHINGTON, September 5, 1911.

RESULTS OF STEAM-CURING TESTS OF PORTLAND CEMENT MORTARS (TABLES 1 TO 6)

TABLE 1

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water). Tested when two days old

Cyl. No.	Steam: Gage pressure, lbs. per sq. in.	Steam: Temperature, °F.	Duration of steam treatment by hours	Weight, lbs. per cu. ft.: Before steam treatment	Weight, lbs. per cu. ft.: After steam treatment	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
1	Not steamed			133.5	.....	33 880	676	.....	1 480 000	250	Bulge at center
2				133.5	.....	29 610	596	.....	.....	.....	Do.
3				132.9	.....	28 710	567	.....	.....	.....	Diagonal shear
Av.				133.3	.....	.....	613	0	.....	.....	
4	Atm.	212	48	.....	.....	62 380	1241	.....	.....	.....	
5				.....	.....	68 570	1364	.....	.....	.....	
6				.....	.....	60 050	1195	.....	.....	.....	
Av.				.....	.....	.....	1267	107	.....	.....	
7	2	218	24	133.2	131.1	87 660	1743	.....	1 900 000	800	Bulge at center
8				132.3	130.2	91 430	1810	.....	.....	.....	Do.
9				132.3	130.2	94 970	1870	.....	.....	.....	Do.
Av.				132.6	130.5	.....	1808	195	.....	.....	
10	10	239	24	132.1	129.4	83 500	1649	.....	1 460 000	700	Do.
11				132.9	130.8	89 260	1775	.....	.....	.....	Do.
12				133.8	131.1	97 315	1934	.....	.....	.....	Do.
Av.				132.9	130.4	.....	1786	191	.....	.....	
13	20	258	24	134.0	132.4	107 160	2113	.....	2 000 000	1100	Diagonal shear
14				133.2	131.1	112 310	2235	.....	.....	.....	Bulge at center
15				134.7	132.6	108 140	2070	.....	.....	.....	Do.
Av.				134.0	132.1	.....	2139	249	.....	.....	
16	40	286	24	132.6	129.4	162 930	3251	.....	2 900 000	800	Do.
17				131.1	129.5	160 490	3143	.....	.....	.....	Do.
18				132.3	130.7	176 000	3481	.....	.....	.....	Do.
Av.				132.0	129.9	.....	3292	437	.....	.....	
19	80	323	24	131.8	130.2	200 000	3959	.....	2 840 000	1500	
20				133.5	130.3	[1] 200 000+	3966+	.....	.....	.....	
21				131.8	129.7	[1] 200 000+	3966+	.....	.....	.....	
Av.				132.4	130.1	.....	3964+	547+	.....	.....	
22	80	323	24	133.3	130.1	224 650	4435	.....	.....	.....	
23				132.4	130.3	211 840	4185	.....	.....	.....	
24				131.1	129.0	246 360	4840	.....	.....	.....	
Av.				132.3	129.8	.....	4487	632	.....	.....	

[1] Beyond capacity of machine. Tested when 15 days old=4524 and 4655.

TABLE 2.

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water). Tested when seven days old

Cyl. No.	Steam: Gage pressure, lbs. per sq. in.	Steam: Temperature, °F	Duration of steam treatment, hours	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure.
25[8]	Not steamed			.....	67 860	1345	.....	1 995 000	500	Bulge at center
26[8]				.....	62 030	1240	.....	.....	.....	Do.
27[8]				.....	65 430	1302	.....	.....	.....	Do.
Av.	.....	.....	.....	.....	.....	1296	0	.....	.....	
28	2	218	24	133.0	84 000	1671	.....	2 040 000	800	Do.
29				132.2	95 490	1889	.....	.....	.....	Do.
30				132.0	91 140	1815	.....	.....	.....	Do.
Av.	.....	.....	.....	132.4	.....	1792	38.3	.....	.....	
31	10	239	24	132.3	81 960	1622	.....	1 450 000	1000	
32				130.7	76 420	1508	.....	.....	.....	Do.
33				131.5	77 770	1535	.....	.....	.....	Do.
Av.	.....	.....	.....	131.5	.....	1555	20.0	.....	.....	
34	20	258	24	134.5	113 850	2259	.....	2 100 000	1100	Do.
35				135.0	118 210	2351	.....	.....	.....	Do.
36				133.3	112 810	2241	.....	.....	.....	Do.
Av.	.....	.....	.....	134.3	.....	2284	76.2	.....	.....	
37	40	286	24	135.4	180 140	3583	.....	3 660 000	700	
38				132.7	174 660	3450	.....	.....	.....	
39				133.3	156 000	3109	.....	.....	.....	
Av.	.....	.....	.....	133.8	.....	3381	160.8	.....	.....	
40	80	323	24	135.0	[9] 200 000+	3966+	.....	3 500 000	1200	
41				134.5	[9] 200 000+	3966+	.....	.....	.....	
42				134.6	[9] 200 000+	3966+	.....	.....	.....	
Av.	.....	.....	.....	134.7	.....	3966+	206.+	.....	.....	
43	80	323	24	133.8	227 700	4529	.....	.....	.....	Do.
44				132.7	185 190	3684	.....	.....	.....	1 corner sheared
45				132.2	218 600	4348	.....	.....	.....	Bulge at center
Av.	.....	.....	.....	132.9	.....	4187	223.0	.....	.....	

[8] Tested when 8 days old; no power at 7 days.
[9] Beyond capacity of machine. Tested when 15 days old=5,220; 4,660; 4,640; average 4,840.

TABLE 3

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water). Tested when 14 days old

Cyl. No.	Steam: Gage pressure, lbs. per sq. in.	Steam: Temperature, °F	Duration of steam treatment, hours	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength lbs. per sq. in.	Per centage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure.
46	Not steamed			134.4	76 800	1536				Diagonal shear
47				133.5	73 080	1454				Bulge at center
48				134.2	79 800	1595				Do.
Av.				134.0		1528	0			
49	2	218	24	133.8	87 470	1739		2 160 000	1300	Do.
50				133.2	87 200	1754				Diagonal shear
51				132.6	97 190	1923				
Av.				133.2		1805	18.1			
52	10	239	24	132.6	85 360	1690		2 670 000	300	
53				131.4	86 500	1712				
54				130.6	85 940	1700				
Av.				131.5		1701	11.3			
55	20	258	24		141 040	2806				
56					138 020	2746				
57					134 100	2668				
Av.						2740	51.8			
58	40	286	24	134.1	179 100	3535				
59				134.4	175 000	3450				
60				133.6	176 690	3468				
Av.				134.0		3484	128.0			
61	80	323	24		[10] 206 500	4108				
62					[11] 216 175	4300				
63					245 910	4892				
Av.						4433	190.0			

[10] Not sprinkled after steam treatment.
[11] Machine stopped and specimen failed while standing under this load.

TABLE 4

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water)

Cyl. No.	Steam: Gage pressure, lbs.per sq. in.	Steam: Temperature, °F.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Character of failure
64	Not steamed			28	134.2	86 610	1723	Diagonal shear
65				28	133.5	82 220	1636	Bulge at center
66				28	133.3	91 580	1822	Do.
Av.					133.7		1727	
67	Not steamed			90			[12] 2286	
70				180			[13] 2342	
73	2	218	24	113	134.2	164 770	3269	
74				113		175 120	3493	
75				113	134.7	167 750	3330	
Av.					134.4		3364	
76	10	239	24	28	134.0	92 110	1832	
77				28	133.1	101 340	2015	
78				28	133.2	93 650	1858	
Av.					133.4		1902	
79	20	258	24	110	132.6	175 270	3480	
80				297	130.8	205 160	4065	Do.
81				297	130.6	192 680	3815	Do.
82	40	286	24	105	133.0	239 500	4765	
83				84	132.6	192 570	3813	
84				84		209 450	4189	
Av.					132.8			
85	80	323	24	89	135.8	246 100	4900	
86				89	137.0	251 510	5005	
87				89	136.1	258 550	5145	
Av.					136.3		5017	
88	80	323	24	77	135.1	256 350	5100	
89				77	135.6	266 770	5307	
90				77	135.5	239 000	4754	
Av.					135.4		5054	
91	80	323	24	210		[14] 268 510	5341	

[12] Average of ten test pieces—maximum, 2488; minimum, 2125.
[13] Average of ten test pieces—maximum, 2591; minimum, 2156.
[14] Exposed to weather from November to June.

TABLE 5

One part Portland cement to four parts Meramec River sand. Damp consistency (5½ per cent water). Steam at 80 pounds per square inch gage pressure

Cyl. No.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
92	[15]	2	124.4	28 000	552	.....	1 990 000	100	Bulge at center
93			127.2	28 800	576	.....	.....	.....	Diagonal shear
94			125.7	27 140	543	.....	.....	.....	Do.
Av.			125.8	.....	557	0	.....	.....	
95	3	2	114.9	25 960	513	.....	525 000	300	Bulge at center
96			115.4	24 940	496	.....	.....	.....	Do.
97			115.2	25 880	512	.....	.....	.....	Do.
Av.			115.2	.....	507	− 9	.....	.....	
98	6	2	118.2	29 120	579	.....	585 000	400	
99			117.3	29 010	578	.....	.....	.....	
100			117.4	24 010	478	.....	.....	.....	
Av.			117.6	.....	545	− 2	.....	.....	
101	12	2	125.5	112 500	2228	.....	2 170 000	.....	Do.
102			125.7	123 800	2452	.....	.....	.....	Do.
103			126.8	129 300	2573	.....	.....	.....	Do.
Av.			126.0	.....	2418	334	.....	.....	
104	24	2	131.4	77 680	1557	.....	1 510 000	800	Do.
105			130.9	78 560	1553	.....	.....	.....	Do.
106			127.2	80 380	1593	.....	.....	.....	Do.
Av.			129.8	.....	1571	182	.....	.....	
107	[15]	7	126.7	61 820	1231	.....	1 910 000	600	
108			125.9	64 420	1282	.....	.....	.....	Diagonal shear
109			127.6	65 680	1367	.....	.....	.....	Do.
Av.			126.7	.....	1293	0	.....	.....	
110	3	7	121.9	27 800	556	.....	615 000	350	Bulge at center
111			120.0	24 270	483	.....	.....	.....	Diagonal shear
112			121.3	29 430	586	.....	.....	.....	Bulge at center
Av.			121.2	.....	542	− 58	.....	.....	
113	6	7	125.7	30 630	609	.....	545 000	500	
114			127.2	28 590	569	.....	.....	.....	
115			124.2	29 800	593	.....	.....	.....	
Av.			125.7	.....	590	− 54	.....	.....	
116	12	7	131.0	118 420	2357	.....	.....	.....	Do.
117			130.7	119 430	2377	.....	.....	.....	Diagonal shear
118			131.2	113 180	2252	.....	1 870 000	900	Do.
Av.			131.0	.....	2329	80	.....	.....	
119	24	7	130.2	81 700	1617	.....	1 600 000	800	Do.
120			128.0	78 680	1755	.....	.....	.....	Bulge at center
121			128.0	82 220	1636	.....	.....	.....	Do.
Av.			128.7	.....	1669	29	.....	.....	

[15] Not steamed.

TABLE 5—*Continued*

One part Portland cement to four parts Meramec River sand. Damp consistency (5½ per cent water). Steam at 80 pounds per square inch gage pressure—Continued

Cyl. No.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
122	48	7	128.4	87 420	1739	.....	1 470 000	700	Bulge at center
123			129.4	93 810	1876	.....	.....	.....	Do.
124			129.0	84 540	1690	.....	.....	.....	Do.
Av	.....	.....	128.9	.....	1768	36	.....	.....	
125	(15)	14	128.0	81 670	1625	.....	2 540 000	500	
126			129.1	76 080	1514	.....	.....	.....	
127			126.4	65 910	1311	.....	.....	.....	
Av	.....	.....	127.8	.....	1483	0	.....	.....	
128	3	14	122.5	34 140	676	.....	755 000	400	
129			123.9	33 100	657	.....	.....	.....	
130			125.7	35 210	699	.....	.....	.....	
Av	.....	.....	124.0	.....	677	− 54	.....	.....	
131	6	14	127.0	29 350	582	.....	570 000	400	
132			123.7	31 270	614	.....	.....	.....	
133			127.1	27 870	552	.....	.....	.....	
Av	.....	.....	125.9	.....	583	− 61	.....	.....	
134	12	14	133.6	124 880	2485	.....	2 490 000	500	Do.
135			133.0	121 780	2424	.....	.....	.....	Do.
136			130.5	115 500	2298	.....	.....	.....	Do.
Av	.....	.....	132.4	.....	2402	62	.....	.....	
137	24	14	129.4	79 160	1575	.....	1 390 000	800	Do.
138			129.8	76 780	1527	.....	.....	.....	Diagonal shear
139			125.8	70 160	1396	.....	.....	.....	Bulge at center
Av	.....	.....	128.3	.....	1499	01	.....	.....	
140	48	14	127.5	96 720	1924	.....	.....	.....	Do.
141			128.3	97 120	1932	.....	.....	.....	
142			128.4	80 000	1584	.....	1 710 000	600	Do.
Av	.....	.....	128.1	.....	1813	22	.....	.....	
143	(15)	28	128.8	96 250	1915	.....	2 720 000	600	
144			132.2	118 050	2350	.....	.....	.....	
145			129.3	91 970	1830	.....	.....	.....	
Av	.....	.....	130.1	.....	2032	0	.....	.....	
146	3	28	121.5	34 250	680	.....	.....	.....	Do.
147			124.9	35 100	695	.....	.....	.....	Do.
148			123.8	36 100	715	.....	780 000	400	Do.
Av	.....	.....	123.4	.....	697	− 66	.....	.....	
149	6	28	124.1	35 050	697	.....	.....	.....	Do.
150			124.8	33 550	667	.....	.....	.....	Do.
151			126.5	34 520	689	.....	885 000	350	Do.
Av	.....	.....	125.1	.....	684	− 66	.....	.....	

[15] Not steamed.

TABLE 5—*Continued*

One part Portland cement to four parts Meramac River sand. Damp consistency (5½ per cent water). Steam at 80 pounds per square inch gage pressure—Continued

Cyl. No.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
152	12	28	130.2	110 000	2490	.....	2 740 000	500	Bulge at center
153			132.4	129 780	2584	.....	.....	.....	Do.
154			132.6	133 430	2657	.....	.....	.....	Do.
Av.	.....	.....	131.7	.....	2477	22	.....	.....	
155	24	28	130.4	92 760	1855	.....	1 425 000	1000	Do.
156			130.4	85 900	1518	.....	.....	.....	Diagonal shear
157			129.3	96 580	1912	.....	.....	.....	Bulge at center
Av.	.....	.....	130.1	.....	1762	− 13	.....	.....	
158	48	28	127.7	96 880	1927	.....	1 770 000	800	Diagonal shear
159			128.1	84 460	1672	.....	.....	.....	Bulge at center
160			128.0	98 360	1952	.....	.....	.....	Do.
Av.	.....	.....	127.9	.....	1850	− 9	.....	.....	

TABLE 6.

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water). Steam at 80 pounds per square inch gage pressure.

Cyl. No.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
1[16]	([17])	2	133.5	33 880	676	.....	1 480 000	350	Bulge at center
2[16]			133.5	29 810	596	.....	.....	.....	Do.
3[16]			132.9	28 710	567	.....	.....	.....	Diagonal shear
Av.	.....	.....	133.3	.....	613	0	.....	.....	
161	3	2	122.6	34 020	675	.....	585 000	400	Bulge at center
162			122.1	35 180	696	.....	.....	.....	Do.
163			123.7	36 910	731	.....	.....	.....	Do.
Av.	.....	.....	123.1	.....	701	14	.....	.....	
164	12	2	130.3	163 050	3247	.....	.....	.....	Do.
165			128.3	144 200	2864	.....	.....	.....	Do.
166			129.7	155 000	3108	.....	.....	.....	Do.
Av.	.....	.....	129.4	.....	3073	401	.....	.....	
167	17	2	129.5	158 460	3152	.....	2 090 000	2000	Do.
168			128.8	160 620	3148	.....	.....	.....	Do.
169			129.5	158 420	3105	.....	.....	.....	Do.
Av.	.....	.....	129.3	.....	3135	411	.....	.....	

[16] These results are taken from Tables 1 to 4, test pieces being made with first series. [17] Not steamed.

TABLE 6—*Continued*

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water). Steam at 80 pounds per square inch gage pressure—Continued

Cyl. No.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
170	24	2	129.8	162 000	3239	.....	.....	.....	Bulge at center
171			129.5	159 840	3180	.....	1 870 000	2300	Do.
172			129.2	165 680	3288	.....	.....	.....	Do.
Av.	.....	.....	129.5	.....	3236	428	.....	.....	
251618	(17)	8	133.5	67 860	1345	.....	1 995 000	500	Do.
261618			133.0	62 030	1240	.....	.....	.....	Do.
271618			133.8	65 430	1302	.....	.....	.....	Do.
Av.	.....	.....	.....	.....	1296	0	.....	.....	
173	3	7	128.7	36 640	729	.....	705 000	450	
174			129.3	36 650	729	.....	.....	.....	Do.
175			130.2	36 140	717	.....	.....	.....	Do.
Av.	.....	.....	129.4	.....	725	— 44	.....	.....	
176	12	7	133.0	160 300	3194	.....	.....	.....	Do.
177			133.3	164 520	3273	.....	.....	.....	Do.
178			133.4	145 120	2890	.....	.....	.....	Do.
Av.	.....	.....	133.2	.....	3119	141	.....	.....	
179	17	7	130.1	170 440	3391	.....	2 250 000	1000	Do.
180			131.0	181 360	3610	.....	.....	.....	Do.
181			131.9	155 340	3100	.....	.....	.....	Do.
Av.	.....	.....	131.0	.....	3367	160	.....	.....	
182	24	7	130.9	171 120	3379	.....	2 220 000	1900	Do.
183			129.4	164 300	3271	.....	.....	.....	Diagonal shear
184			130.4	181 940	3612	.....	.....	.....	Bulge at center
Av.	.....	.....	130.2	.....	3421	164	.....	.....	
185	48	7	130.6	212 880	4235	.....	2 380 000	1800	Do.
186			130.3	211 140	4180	.....	.....	.....	Do.
187			129.8	169 840	3379	.....	.....	.....	Do.
Av.	.....	.....	130.2	.....	3931	303	.....	.....	
4616	(17)	14	134.4	76 800	1536	.....	3 700 000	400	Diagonal shear
4716			133.5	73 080	1454	.....	.....	.....	Bulge at center
4816			134.2	79 800	1595	.....	.....	.....	Do.
Av.	.....	.....	134.0	.....	1528	0	.....	.....	
188	3	14	128.3	42 570	847	.....	980 000	200	Do.
189			129.6	43 020	858	.....	.....	.....	Do.
190			130.1	42 840	852	.....	.....	.....	Do.
Av.	.....	.....	129.3	.....	852	— 44	.....	.....	

[16] These results are taken from Tables 1 to 4, test pieces being made with first series.
[17] Not steamed.
[18] No power at 7 days; tested when 8 days old.

TABLE 6—*Continued*

One part Portland cement to four parts Meramec River sand. Quaking consistency (9 per cent water). Steam at 80 pounds per square inch gage pressure—Continued

Cyl. No.	Duration of steam treatment, hours	Age when tested, days	Weight, lbs. per cu. ft. when tested	Ultimate load, lbs.	Ultimate strength, lbs. per sq. in.	Percentage gain in strength over untreated	Initial modulus of elasticity, lbs. per sq. in.	Yield point, lbs. per sq. in.	Character of failure
191	12	14	134.8	160 500	3194	.....	3 260 000	450	Diagonal shear
192			135.5	156 720	3120	.....	.....	.....	Bulge at center
193			134.0	147 540	2938	.....	.....	.....	Do.
Av	.....	.....	134.8	.....	3084	102	.....	.....	
194	17	14	132.7	136 900	2718	.....	3 410 000	350	Do.
195			133.6	153 200	3048	.....	.....	.....	Do.
196			134.8	202 400	4048	.....	.....	.....	Do.
Av	.....	.....	133.7	.....	3271	114	.....	.....	
197	24	14	131.5	155 000	3083	.....	2 880 000	500	Do.
198			132.8	169 920	3380	.....	.....	.....	Do.
199			133.0	176 220	3471	.....	.....	.....	Do.
Av	.....	.....	132.3	.....	3311	117	.....	.....	
200	48	14	132.6	207 440	4126	.....	.....	.....	Do.
201			132.1	213 500	4269	.....	.....	.....	Do.
202			131.1	202 280	4045	.....	2 580 000	900	
Av	.....	.....	131.9	.....	4147	171	.....	.....	
64 [16]	(17)	28	134.2	86 610	1723	.....	.....	.....	Diagonal shear
65 [16]			133.5	82 220	1636	.....	.....	.....	Bulge at center
66 [16]			133.3	91 580	1822	.....	3 700 000	300	Do.
Av	.....	.....	133.7	.....	1727	0	.....	.....	
203	3	28	129.7	57 170	1140	.....	.....	.....	Diagonal shear
204			130.8	55 890	1112	.....	.....	.....	Bulge at center
205			128.6	53 830	1071	.....	1 890 000	300	Do.
Av	.....	.....	129.7	.....	1108	— 36	.....	.....	
206	12	28	131.5	167 770	3341	.....	3 570 000	500	Diagonal shear
207			131.1	148 000	2947	.....	.....	.....	Bulge at center
208			136.3	163 430	3252	.....	.....	.....	Do.
Av	.....	.....	133.0	.....	3180	94	.....	.....	
209	17	28	135.8	185 000	3684	.....	3 570 000	500	
210			135.0	175 950	3504	.....	.....	.....	Do.
211			137.0	186 620	3716	.....	.....	.....	Do.
Av	.....	.....	132.6	.....	3635	110	.....	.....	
212	24	28	134.1	211 700	4212	.....	2 900 000	900	Do.
213			134.2	195 880	3917	.....	.....	.....	Do.
214			133.4	166 260	3307	.....	.....	.....	Do.
Av	.....	.....	133.9	.....	3812	121	.....	.....	
215	48	28	132.9	217 740	4332	.....	2 670 000	1500	Do.
216			132.3	202 380	4026	.....	.....	.....	Do.
217			133.3	203 060	4040	.....	.....	.....	Do.
Av	.....	.....	132.8	.....	4136	139	.....	.....	

[16] These results are taken from Tables 1 to 4, test pieces being made with first series.
[17] Not steamed.

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DEPARTMENT OF COMMERCE AND LABOR
BUREAU OF STANDARDS
S. W. STRATTON, Director

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THE DETERMINATION OF CHROMIUM, AND ITS SEPARATION FROM VANADIUM, IN STEELS

By J. R. Cain

While attempting recently to determine chromium in chrome-vanadium steels, difficulties with some of the usual methods were encountered. If a steel containing chromium as chromate and vanadium as vanadate is titrated against ferrous solutions, using ferricyanide to indicate the point at which all the vanadium and chromium are reduced and an excess of titrating solution is present, there is sometimes an indefinite end point, because as soon as some vanadium is reduced to the vanadyl condition this reacts with the ferricyanide indicator, reducing it to ferrocyanide which then gives the usual color with the ferric salts present.[1] An experienced operator can often judge the end point sufficiently closely for practical work, but the difficulty increases with increasing vanadium, and it is almost always necessary to run blanks of various kinds, increasing to that extent the uncertainties of such methods. If the excess of ferrous solution is titrated back with permanganate, some correction is also necessary for chromium oxidized by permanganate.[2] If in the preliminary oxidation of the vanadium and chromium, any manganese dioxide separates, as where potassium permanganate or potassium

[1] Cain: J. Ind. and Eng. Chem., 8, p. 476; 1911; other references will be found here.
[2] Cain, loc. cit.

chlorate are used, some chromium may be, and often is, carried down by the manganese.[3] If, in order to separate vanadate from chromate, the nitric acid solution of the steel (with or without preliminary ether extraction of most of the iron) is poured into excess of sodium hydroxide solution and boiled, usually an appreciable amount of chromium goes into the filtrate with the vanadium. Many methods take no account of this chromium. The amount so lost increases with the manganese in the steel and the time of boiling, the manganese being converted in part to peroxide and this, in the strongly alkaline solution, oxidizing the chromium to chromate.[4]

Many careful tests having shown that chromium in much larger amount than the usual commercial steels carry can be precipitated completely in a few minutes by boiling the nearly neutralized (ferrous) solution of the steel with barium carbonate, cadmium carbonate, zinc oxide or magnesium oxide, it was decided to base a method for determining chromium on one of these methods of separation from iron. Probably the reason why such separations have not come into more general use is because practically all writers have directed the making of carbonate or oxide precipitation in the cold, which requires many hours' standing and is even then sometimes incomplete. The work done here has shown that but 10 or 15 minutes' boiling, with proper precautions, is all that is ever necessary, the filtrates being free from even traces of chromium (or vanadium).

Noyes and Bray [5] have given conditions for completely precipitating chromates in the presence of vanadates which make possible a good separation of the two elements. The work here having completely confirmed their results, this separation was incorporated in the method.

DESCRIPTION OF THE METHOD

Dissolve in a covered 300-cc Erlenmeyer flask an amount of drillings, which will give not to exceed 6 or 7 centigrams of chromium, using about 10 cc of concentrated hydrochloric acid

[3] Arnold and Ibbottson, Steel Works Analysis, 3d ed., p. 180, also Cain, loc. cit.
[4] Cain, loc. cit.
[5] Technology Quarterly, 21, p. 14, 1908.

per gram of steel. The concentrated acid (specific gravity 1.20) seems to dissolve the steel much more readily than a diluted acid. When no more hydrogen is given off, dilute to 100 or 150 cc with hot water, nearly neutralize with saturated sodium carbonate solution, add barium carbonate emulsion in slight excess, place on the hot plate and boil vigorously 10 or 15 minutes, with small additions of the barium carbonate emulsion every two or three minutes. The flask should be kept covered during all operations so as to exclude air as completely as possible. Too great an excess of barium carbonate should not be used, as this increases the difficulty of extracting the chromium in the subsequent fusion. An excess of a gram or two is the most that should be present. Remove the flask from the plate, let the precipitate settle, and filter at once on an 11-cm white label No. 589, filter, washing twice with hot water. These operations should be carried out rapidly and without delay. Place the filter and precipitate in a sufficiently large platinum crucible, burn off the filter, add 2 grams of sodium carbonate and about one-fourth of a gram of potassium nitrate, and fuse for 20 minutes. Place the inverted and inclined crucible on a glass triangle, which has glass legs about three-fourths of an inch long fused to its corners for supports; triangle and crucible are put into a 250-cc beaker, covered with boiling water, and the contents of the beaker digested a few minutes until the fusion is disintegrated. Filter into a flask, add 1 or 2 cc of hydrogen peroxide to the filtrate and boil for 5 or 10 minutes to destroy the excess of peroxide. Cool, transfer to a 250 or 300-cc separatory funnel, add a slight excess of nitric acid (1–1), and shake vigorously a few minutes, allowing the liberated carbon dioxide to escape by inverting the separatory funnel and opening the stopcock. Transfer to a 250-cc beaker, just neutralize with sodium hydroxide solution, and then add nitric acid (1–1), 2 cc for each 100 cc of solution. Add 20 cc of a 20-per cent lead nitrate solution to the cold solution, stirring vigorously. The precipitate settles quickly. It is filtered on asbestos, and washed three or four times with cold water. The asbestos mat is transferred to a beaker or flask, and the lead

chromate decomposed with hot hydrochloric acid (1–4). The solution is cooled, the volume made up to 150 or 200 cc, and it is titrated against approximately N/10 ferrous sulphate solution with ferricyanide as outside indicator. Or, if desired, an excess of the ferrous sulphate solution is added and the excess titrated back against bichromate. The standard iron solution should be compared with bichromate or permanganate on the day it is used. Table I gives results obtained with synthetic solutions and with the chrome-vanadium standard steel of the Bureau of Standards.

The synthetic solutions were made by adding the chromium from a carefully standardized bichromate solution and the vanadium from a sodium-vanadate solution to the hydrochloric-acid solution of a steel free from vanadium and chromium.

Table I

Experiment	Iron present	Vanadium present	Chromium present	Chromium found	Difference
	Gram				
1	1	0.0012	0.0140	0.0137	—0.0003
2	1	.0024	.0280	.0277	— .0003
3	1	.0024	.0420	.0420	.0000
4	1	.0036	.0560	.0558	— .0002
5	1	.0048	.0700	.0700	.0000
6	1	.0060	.1120	.1122	+ .0002
7	1	.0120	.1680	.1685	+ .0005
8	1	.0180	.2800	.2805	+ .0005
[6] 9	4			.0536	

[6] Chrome-vanadium standard; 4 determinations; each gave 1.34 per cent. Average of results of cooperating analysts: Chromium, 1.36 per cent; vanadium, 0.204 per cent.

NOTES AND PRECAUTIONS

Numbers 6, 7, and 8 of Table I show that very large amounts of chromium can be completely precipitated by the barium-carbonate method carried out as above described. However, if the amount of chromium exceeds that recommended in the method described herein it can not be readily extracted by 2 grams of sodium carbonate, particularly if too great an excess of barium is present. The amount of sodium carbonate used was governed by

the directions of Noyes and Bray,[7] who state that for a successful separation of chromium not too much sodium nitrate should be present. The separations described herein were made in a volume of 250 cc, and inasmuch as 2 grams of sodium carbonate was used for fusions the resulting sodium nitrate concentration was about 1.3 grams per 100 cc. The filtrates were tested for chromium by removing the excess of lead with sulphuric acid, filtering, concentrating to about 10 or 15 cc, and making alkaline with sodium hydroxide. No color indicative of chromate was ever obtained, even after adding a little hydrogen peroxide and boiling to oxidize any chromium that may have been reduced. Possibly the larger amounts of chromium could have been completely extracted by one fusion had more sodium carbonate been used, but the manipulation is then less convenient. Moreover, with the usual range of chromium content in commercial steels one need never work with more than 7 or 8 centigrams to secure an accurate determination.

The boiling with hydrogen peroxide in alkaline solutions before precipitation with lead nitrate is done in order to destroy any nitrite formed during the fusion. If this were present when the solution is acidified, the resulting nitrous acid would possibly reduce some chromium or vanadium. Five minutes' boiling will insure destruction of the excess of peroxide if only 2 or 3 cc of the usual 3-per cent solution used. The hydrogen peroxide should be completely removed before acidifying, inasmuch as it reduces chromic acid.[8]

The freeing of the solution from carbon dioxide is an important step, for if this is not done the precipitate does not settle out rapidly and is not so easy to filter; shaking in a separatory funnel, as described, is a convenient way of accomplishing this.

The solutions containing the chromium after titration were treated with enough sulphuric acid to precipitate the lead, which was filtered off and washed with dilute sulphuric acid. The filtrates were evaporated on the hot plate until free from hydrochloric acid and then electrolyzed with a mercury cathode[9] until

[7] Cain, loc. cit., p. 48, note 4.
[8] Perchromic acid is first formed, but is rapidly decomposed.
[9] Cain, loc. cit.

free from iron and chromium. The solution in the electrolyzing apparatus was then tested for vanadium by hydrogen peroxide, none being found in most cases and in others only traces, showing that the separation under the conditions given is practically perfect.

It is well to examine the insoluble matter resulting from the fusion for chromium by again fusing it with sodium carbonate and potassium nitrate. The solution from the second fusion is almost invariably colorless when working under the conditions herein recommended. Should there be a slight yellow color, however, the chromium causing it can be estimated colorimetrically. A determination of chromium can easily be made in one and one-half hours.

CONCLUSIONS

1. Sources of error in some of the usual methods for determining chromium in chrome or chrome-vanadium steels, which limit the accuracy of the results, are described.

2. The precipitation of chromium from solutions of steels and its separation from practically all the iron can be effected quickly and easily by boiling with a number of precipitants, herein described.

3. The chromium may be readily extracted from the precipitates by fusion and separated from vanadium by precipitating as lead chromate under the conditions prescribed.

WASHINGTON, November 1, 1911.

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No. 8

A RAPID METHOD FOR THE DETERMINATION OF VANADIUM IN STEELS, ORES, ETC., BASED ON ITS QUANTITATIVE INCLUSION BY THE PHOSPHOMOLYBDATE PRECIPITATE

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1. INTRODUCTION

The fact that vanadium is carried down with ammonium phosphomolybdate when the latter is precipitated in solutions of the former has long been known. Likewise, the fact that the precipitate so obtained has different properties from the normal phosphomolybdate has been mentioned by several authors. The orange to brick-red color of this vanadium-bearing precipitate is quite different from the color of the normal ammonium phosphomolybdate—called from its color the "yellow precipitate." Brearley and Ibbotson [1] mention the increased solubility in dilute nitric acid of the vanadium-bearing precipitate over the normal precipitate and give some conditions to lessen precipitation of vanadium with phosphorus in steel analysis. The phenomenon has usually been studied with regard to the determination of

[1] The Analysis of Steel-Works Materials, 1902, p. 165.

phosphorus in the presence of vanadium, since the precipitation of vanadium with ammonium phosphomolybdate interferes with an exact determination of phosphorus by the ordinary methods. Especially is this true in steel analysis. The possibility of easily separating vanadium from iron by this method has, we believe, never before been studied. The present research was undertaken in order to decide whether or not vanadium could be completely precipitated with phosphoric acid; and, if so, to learn if it could be determined quantitatively.

2. PRELIMINARY CONDITIONS FOR PRECIPITATING THE VANADIUM

The necessary ratio of phosphoric acid to vanadic acid for complete precipitation of the latter was investigated qualitatively by following the change in color of the phosphomolybdate precipitated with increasing additions of phosphoric acid. A nitric acid solution of a vanadium-free steel was prepared; to this was added a known amount of vanadium from a carefully standardized ammonium vanadate solution. To equal volumes of the steel solution so prepared were added gradually increasing volumes of a roughly standardized sodium phosphate solution, and the phosphoric acid was precipitated by the molybdate reagent, observing the conditions for this precipitation usually given in texts on steel analysis. With small amounts of phosphoric acid the precipitate was of a deep orange color, which became progressively lighter as the phosphorus increased, finally approaching the color of the normal or vanadium-free phosphomolybdate when relatively very large amounts of phosphoric acid were added. The filtrates were treated by precipitating a further small amount of phosphoric acid, and judging by the color of the precipitate whether or not precipitation was complete the first time. The color of the precipitate proved to be a very delicate qualitative criterion, and very soon it was possible in this manner to fix with fair accuracy the ratio of phosphoric acid to vanadic acid in order to carry down all the vanadium with one precipitation. As methods for the quantitative determination of the vanadium were developed, this ratio

was determined with greater accuracy. The mechanism of the precipitation and the question of this ratio are subjects that will be described in more detail in another paper. It is sufficient for the present purpose to say there is a coprecipitation of vanadium under the above general conditions, which can be accurately enough controlled to make the precipitation uniformly quantitative.

Other questions affecting the probable accuracy of the determination were (1) solubility of the vanadium-bearing precipitate in the usual washing solutions, and (2) the optimum temperature for precipitation. As to the solubility of the precipitate, it was soon found that the presence of vanadium caused marked changes in the solubility of ammonium phosphomolybdate. It was noticed that when the precipitate dissolved to any extent in the washing solutions, these were strongly colored, usually having a straw or orange tint. It was thus possible to decide the question qualitatively, and Table I gives some of the results obtained. It will be seen that acid ammonium sulphate and ammonium nitrate solutions are best adapted for washing the yellow precipitate. Incidentally, the marked solubility in dilute solutions of potassium nitrate and of nitric acid is of interest, for these are the wash solutions recommended by some authorities for use when determining phosphorus in steel. It is evident that such use may occasion errors in the phosphorus determination if vanadium is present in appreciable amount. It seems probable that the solubilities vary considerably with the proportion of vanadium present in the precipitates.

TABLE I

Order of Solubility of Vanadium-Bearing Precipitate[2] in Various Solvents at Room Temperature

Solvent	Concentration	Color of solution
	Per cent	
Ammonium acid sulphate	(3)	Colorless.
Ammonium nitrate	(4)	Do.
Do	10	Do.
Ammonium sulphate	50	Faint yellow.
Nitric acid	50	Color increases regularly down the series, showing increasing solubility.
Do	25	
Ammonium sulphate	30	
Ammonium nitrate	1	
Ammonium chloride	1	
Ammonium sulphate	10	
Sulphuric acid	50	
Water		
Ammonium molybdate (neut.)	1	
Potassium nitrate	1	
Potassium sulphate[5]	1	Deep yellow (complete solution).
Nitric acid[5]	1	
Sodium sulphate[5]	1	
Ammonium molybdate (neut.)[5]	10	

[2] Containing approximately four-tenths of 1 per cent vanadium.

[3] See p. 15.

[4] Saturated solution.

[5] Five-tenths gram of precipitate dissolves in less than 20 cc of the solvent.

The optimum temperature for precipitation in this connection is governed largely by considerations affecting the physical properties of the precipitate and the speed of precipitation. Accordingly, our precipitations are made from solutions brought to boiling before addition of the precipitant, thus securing a rapidly settling precipitate, readily filtered by suction. Certain reasons, to be considered at another time, would seem to demand a precipitation at this high temperature. Brearley and Ibbotson[6] also have shown that more vanadium is precipitated at high than at low temperatures.

After having assured ourselves qualitatively that vanadium is completely precipitated by the phosphomolybdate precipitate

[6] The Analysis of Steel-Works Materials, 1902.

obtained under proper conditions, a study was made of methods for determining the vanadium thus precipitated.

3. SEPARATION OF THE VANADIC ACID FROM THE MOLYBDIC ACID

In view of the easy volatility of molybdic acid, it was at first thought practicable to heat the precipitate over a blast lamp until all the molybdenum had been driven off. It was found that nearly all the molybdenum could be volatilized, but there are too many difficulties encountered to make the method reliable. There is much danger of mechanical loss where the relative amount of vanadium is small; moreover, at the temperature required for rapid volatilization, the vanadium pentoxide remaining behind fuses and creeps over the side of the boat or crucible used as a container, a fact previously noted by Gibbs.[7] Further, there is usually a slight reduction of molybdenum to a lower oxide which does not volatilize readily. However, this method of handling the precipitate has some merits, particularly if one wants visual confirmation of the presence of vanadium in a sample of material. The characteristic appearance of fused vanadium pentoxide is easily distinguished in the residue after ignition, even though some of the lower (blue) oxide of molybdenum is present. Of course this precipitate can be taken up by fusion with sodium carbonate and precipitated by mercurous nitrate or in any other manner desired. Usually it is accompanied by some iron oxide. We consider that the method is subject to too many irregularities and is too difficult of manipulation for technical work. Moreover, it is much slower than other procedures to be described later. We find that Truchot [8] had also proposed and made use of the volatility of molybdic acid to separate it from small amounts of vanadium coprecipitated with molybdenum, when electrolyzing ammoniacal solutions of molybdates and vanadates.

A very much simpler and shorter method has been devised by us for separating the vanadium in pure form from the phosphomolybdate precipitate. The latter is suspended in a small amount of hot water, and dilute ammonia added drop by drop, with vigorous

[7] Am. Chem. J., 5, p. 371; 1883–84.

[8] Ann. Chim. Anal., 7, pp. 165–167; 1902.

shaking, until everything is in solution. The solution is heated until all but a trace of ammonia is expelled. The success of the operation depends on the presence of a very small amount of free ammonia at this stage. If too much is present, the precipitate subsequently obtained on adding mercurous solution carries down some molybdenum. On the other hand, enough ammonia must be present to form a sufficient volume of amido precipitate to bring down the vanadium. One or two trials will enable the operator to decide as to the proper excess. When the right amount of ammonia is present, the solution is filtered, if necessary, and enough mercurous nitrate solution is added to it to give an appreciable acid reaction with litmus paper.[9] Usually a voluminous black precipitate separates on shaking; if it does not form and settle rapidly, the solution is heated until it does. The precipitate is washed by decantation two or three times with water containing 1 per cent mercurous nitrate, and is finally transferred to the filter and washed there two or three times more. Filter and contents are transferred to a porcelain crucible, the filter paper burned off, and the mercury volatilized. The vanadium remains partly as vanadic pentoxide, partly as lower oxides and is accompanied by relatively very little molybdenum. The latter may be precipitated, if desired, by hydrogen sulphide (after the vanadium has been dissolved out of the crucible with concentrated sulphuric acid and the solution diluted) leaving a pure vanadium solution. If the vanadium pentoxide is dissolved out of the crucible with concentrated sulphuric acid, the intense brown or orange color, characterizing such solutions of vanadium pentoxide is very marked; if blue or green tints (due to lower oxides of molybdenum and vanadium) are present, these disappear on the addition of a trace of nitric acid, and evaporation until dense fumes appear.

We have not used this method for obtaining quantitative separations of vanadium, although it would probably be successful if the filtrates were treated a second or third time and the precipitates combined. However, by far the greater portion of the vanadium is obtained at first.

[9] Caused by the hydrolysis of the mercurous nitrate solution.

The principal use we have made of these methods, as stated above, has been for the purpose of actually isolating the vanadium where there could be the slightest doubt as to its being present at all. In this manner, we believe, the value of the method, from a purely scientific standpoint, is increased. For technical or practical purposes it is never necessary to separate the vanadium from the molybdic and phosphoric acids in order to determine it accurately.

4. REDUCTION OF THE VANADIC ACID BY SULPHUR DIOXIDE

Edgar's [10] method of reduction by sulphur dioxide was next tried, with the idea of reducing the vanadium to the tetravalent stage without affecting the molybdenum; the tetravalent vanadium could then be titrated against permanganate, as usual. Edgar found that by properly adjusting the acidity (sulphuric acid) of his solution, and its molybdenum concentration, the differential reduction could be made with ease. Our results are confirmatory, but unfortunately the method is limited in its application to the present problem because of the effect of the presence of iron occluded by the large amount of ammonium phosphomolybdate sometimes required. This iron is sometimes present in relatively large quantities and of course is wholly or in part reduced by the sulphur dioxide. It is difficult, too, to completely eliminate this impurity from the precipitate without unduly prolonging the process. Solution of the precipitate, followed by reprecipitation, helps but little. If the precipitate is dissolved in ammonia, a clear solution is obtained, even if considerable iron is present; the latter reveals its presence by imparting a dark color to the otherwise colorless solution. If, however, the precipitate is dissolved in sodium hydroxide, a large proportion of the iron separates and the precipitation can be made nearly complete by boiling the solution until all the ammonia of constitution of the yellow precipitate is expelled.

[10] Am. J. Sci., 4th series, 25, pp. 332–334, 1908. (See also Gibbs, loc. cit.)

We made a number of fairly accurate determinations of vanadium in the presence of iron and chromium by precipitating the vanadium with phosphomolybdate, dissolving the precipitate in ammonia, acidifying with sulphuric acid to a 15 per cent acidity, followed by sulphur dioxide reduction and permanganate titration. In most of the determinations it was necessary to get rid of the iron contaminating the phosphomolybdate by dissolving the latter in sodium hydroxide solution and filtering off the ferric hydroxide, as above. It was found that chromium in the trivalent condition did not affect the determination of vanadium at all.

A series of determinations by this method now gave the necessary data for accurately fixing the ratio of phosphorus to vanadium to secure complete precipitation. It was established that 10 times as much phosphorus as there is vanadium to be determined would insure complete precipitation of all the vanadium and allow a sufficient margin of safety for variation from suspected composition. We have used this ratio in all subsequent determinations. Of course, where the vanadium content of a sample is not known within sufficiently close limits, it is necessary to make two or more phosphomolybdate precipitations, testing each for vanadium. However, this is about what one has to do with any method when working on unknown materials.

The method of reducing the vanadium by sulphur dioxide and titrating against permanganate having proved, in our opinion, too long and uncertain for technical use, other methods were tried.

5. COLORIMETRIC DETERMINATION OF THE VANADIC ACID

Gregory's colorimetric method,[11] depending on the colors developed in strong sulphuric-acid solutions of vanadium and strychnine, seemed promising, inasmuch as the phosphomolybdate is so soluble in concentrated sulphuric acid. We found by preliminary tests that the associated molybdenum has no appreciable effect on the strychnine, so far as color development is concerned. However, iron does, and this is to be expected from Allen's state-

[11] Chem. News, **100**, p. 221; 1909.

ment of the cause of the color:[12] "On treating a cold solution of strychnine in concentrated sulphuric acid with an oxidizing agent of almost any kind a rich purple-blue coloration is developed. This changes more or less rapidly through purple and crimson to a bright cherry-red tint, which is somewhat persistent." From this it was evident that ferric iron must be absent and probable that the vanadium must be in the pentavalent state. We confirmed the latter by trials of concentrated sulphuric-acid solutions of V_2O_4, which gave no color with strychnine. This is an important point, for we found that strong sulphuric-acid solutions of vanadium pentoxide are very prone to go over to the quadrivalent state, when of course they develop no color with strychnine. With sulphuric-acid solutions of the phosphomolybdate precipitate containing vanadium, it is easy to follow this change by the change of color in the solution. Initially there is a straw or orange color,[13] apparently due to the presence of acid vanadates or polyacids,[14] which is probably closely proportional to the amount of vanadium present, but after a few minutes evaporation to strong sulphur trioxide fumes, and with low vanadium content, the solution becomes either colorless or a pale blue. We observed the same phenomenon with concentrated-sulphuric acid solutions of vanadium pentoxide. At first the reduction was thought to be due to organic matter present in the sulphuric acid, but further experiments with larger amounts of vanadium showed too much reduction to be accounted for in this way. For instance, in one experiment 8 milligrams of vanadium as pentoxide dissolved in 15 to 20 cc of sulphuric acid was fumed in a carefully covered flask for four or five hours, at the end of which time reduction was practically complete.

We found that Prandtl[15] had already investigated this matter and concluded that under these conditions there is a dissociation of the vanadium pentoxide in analogy to the behavior of chromic anhydride dissolved in concentrated sulphuric acid. The behavior

[12] Commercial Organic Analysis, 2d ed., 3 pt., II, p. 368.

[13] Some work has been done here toward making this color the basis of a colorimetric method for vanadium.

[14] Gmelin-Kraut, Handb. d. Anorg. Ch., 7th Auf., III, 2, p. 89.

[15] Gmelin-Kraut, Loc. cit., p. 87.

was the opposite of what we had expected, after having read the work of Koppel and Behrendt,[16] who found the reverse action taking place. Possibly there is an equilibrium between the two sets of reactions. This complication is very troublesome when attempting to prepare the sulphuric-acid solution of the vanadium-bearing phosphomolybdate for colorimetric estimation by strychnine. As stated above, with small amounts of vanadium (for which we had expected the colorimetric method to be very useful), the reduction or dissociation takes place completely in a few minutes after the precipitate is dissolved in sulphuric acid. Such a solution treated at once with strychnine either gives no color, or a much less intense color than corresponds to the actual amount of vanadium present. On the other hand, if the attempt is made to reoxidize the vanadium to the pentavalent stage, this must be accomplished under difficult conditions, for no excess of the oxidizer must be left in the solution (inasmuch as this would give a color with the strychnine), nor must the solution be heated unduly long in attempting, for instance, to destroy or drive off the excess of oxidizer, for as soon as the excess disappears the vanadium goes quickly to the quadrivalent stage. Thus, while it was easy to oxidize the vanadium with a minute quantity of nitric acid, we could never be sure that the excess had been driven off and at the same time no vanadium had been reduced. We attempted to find an oxidizing agent that would oxidize the vanadium without affecting the strychnine and found that bismuthate would do so under very special sets of conditions, but there were complications attending its use, such as clouding of solutions in the colorimeter, occasional unexplained development of color in blanks, etc., that led us to abandon its use altogether. Besides the uncertainties and complications occasioned by solution in concentrated sulphuric acid already mentioned, which necessitate oxidation with reagents liable to cause high results if used (or low ones if not used), and those arising from the presence of iron with the phosphomolybdate, necessitating reprecipitation, there is also the possible accidental introduction of organic matter at various stages where reduction of vanadium might occur, and the troublesome manipulation of

[16] Zs. Anorg. Chem., 35, p. 156; 1903.

concentrated sulphuric acid in the colorimeter. The colorimetric method of determining vanadium in the precipitate at first appealed to us because of its apparent simplicity and wide range of application, but the results of an extended series of determinations lead us, for the present at least, to abandon these views.

6. REDUCTION OF THE VANADIUM BY HYDROGEN PEROXIDE

(a) GENERAL

In attempting to find a suitable oxidizer for preparing the vanadium solutions for colorimetric determination we tried hydrogen peroxide, and were thus led to the discovery of the reaction which is made the basis of the method we have finally adopted for determining vanadium in the phosphomolybdate precipitates. Much to our surprise, the peroxide, used in concentrated sulphuric acid solutions, acted as a reducing instead of an oxidizing agent, so that by its use we were able to easily reduce the vanadium quantitatively to the tetravalent stage. Moreover, we found by careful tests that the associated iron and molybdenum were never affected. We found that solid peroxides could be used, but hydrogen peroxide is to be preferred, in general. The details of the reaction will be given fully in another paper, and only stated here in so far as they apply to the method of analysis. To carry out the reduction all that is necessary is to dissolve the phosphomolybdate-vanadium precipitate in concentrated sulphuric acid (filtration having been made on asbestos), add a few drops of nitric acid, fume strongly for two or three minutes, remove from the hot plate, allow to cool, and add hydrogen peroxide in very small quantities, with vigorous shaking after each addition, until the solution takes on a deep brown color (due to action on the molybdate); this always disappears on heating, and is followed by the clear green or blue color (depending on the ratio of V to Mo) of vanadyl vanadium. The flask is replaced on the hot plate and the solution fumed for a few minutes, after which it is cooled, diluted, and titrated against permanganate. The whole operation is extremely simple, the end point very good, and as our data show, the results are very accurate.

(b) **THE METHOD**

For Steels Containing Vanadium, Chromium, Nickel, Titanium, Manganese, Molybdenum, Singly, or in Combination.—Dissolve an amount of drillings estimated to contain 2 to 10 mg of vanadium in nitric acid (sp. gr. 1.135), boil till free from fumes, oxidize with permanganate solution, dissolve the separated manganese peroxide in sodium sulphite solution, and boil till free from fumes. In other words, prepare the solution exactly as for a phosphorus determination, examining any residue for vanadium. Nearly neutralize with ammonium hydroxide (0.96) and add an amount of sodium phosphate solution containing at least 10 times as much phosphorus as there is vanadium present. Bring the solution to boiling, remove from the plate and add at once the usual necessary excess of the molybdate reagent to precipitate the amount of phosphoric acid added. Agitate for a minute or so, when it will be found that the precipitate settles rapidly. Filter the supernatant liquid by suction through an asbestos filter, and wash three times by decantation with hot acid ammonium sulphate solution, pouring the washing liquid through the filter. The last wash solution should be decanted off as completely as possible from the precipitate in the flask and the filter should be sucked dry. The rubber stopper carrying the filter is now fitted to a small, dry, bottle and hot concentrated sulphuric acid is poured on the filter to dissolve the small amount of precipitate thereon. This dissolves quickly, and the solution is drawn through by suction into the bottle. The contents of the bottle are transferred to the flask in which precipitation was made, and the bottle is washed once with concentrated sulphuric acid, the washings being added to the flask. For every 10 mg of phosphorus present a final volume of 5 to 8 cc of concentrated sulphuric acid is necessary. The contents of the flask are heated until solution takes place, a few drops of nitric acid (1:25) are added, the heating is continued, and when fumes are coming off strongly, the flask is removed from the plate and the vanadium reduced by successive small additions of hydrogen peroxide, as above described. Replace on the hot plate, fume for four or five minutes, cover the flask, cool, dilute

so as to secure an acidity of one part to five by volume, and titrate at a temperature of 70° to 80° C against 0.01 N permanganate. The conditions as to acidity and temperature must be closely observed in order to secure a satisfactory end point.

For Steels of the Above Classes Containing Tungsten.—The only change necessary is to dissolve in aqua regia, dilute with hot water, filter off the tungstic acid, nearly neutralize with ammonium hydroxide, and add 10 g solid ammonium nitrate for every 100 cc of the final volume [17] before precipitating as above described. If desired, the tungstic acid on the filter may be dissolved in a small amount of sodium hydroxide solution (free from vanadium), acidified with nitric acid, and tested for vanadium by hydrogen peroxide. We have not found vanadium here and accordingly make no provision for its determination.

(C) SOLUTIONS NECESSARY

Nitric Acid of Sp. Gr. 1.135.—Use 20–25 cc for each gram of drillings to be dissolved.

Potassium Permanganate, for Oxidations, 15 grams per liter.

Sodium Sulphite, 50 grams per liter. A solution of sulphurous acid may be substituted.

Sodium Phosphate, 124 grams $Na_2HPO_4.12\ H_2O$ per liter. One cubic centimeter contains approximately 10 mg of phosphorous and will precipitate 1 mg of vanadium. The solution may be standardized by evaporating a definite volume to dryness, igniting the residue, and weighing the $Na_4P_2O_7$ so formed.[18]

Molybdate Reagent.—Made up according to the usual formulas, 1 cc will contain 0.05 to 0.06 g MoO_3. For every mg of phosphorus to be precipitated use at least 2 cc of molybdate reagent. This ratio is used, however, only when precipitating large amounts of phosphorus. When precipitating small quantities of phosphorus 50 cc of molybdate solution is the minimum volume used.

Acid Ammonium Sulphate.—To 1000 cc of water add 15 cc of ammonium hydroxide (0.90) and 25 cc of sulphuric acid (1.84).[19] Use at a temperature of 80° C.

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[17] Bureau of Chemistry Bull. No. 107 (revised), p. 3.

[18] Baxter: Am. Chem. J., 28, p. 301; 1902.

[19] Blair: The Chemical Analysis of Iron, 7th ed., p. 97.

Potassium Permanganate, 0.01N.—Standardize against sodium oxalate,[20] or, empirically, against a steel in which the vanadium has been accurately determined by other methods.

Peroxide.—Hydrogen peroxide, 3 per cent; we have made our reagent with "Perhydrol." "Dioxogen" also proved satisfactory.

Table II shows a few of the very large number (in all nearly 400) of determinations made by us to be sure that the method is reliable. Nos. 16 and 17 of the same table are of interest as showing the delicacy of the method. As a matter of fact, the vanadium can just as easily be concentrated from 50 or even 100 g of steel or iron, so that excessively small percentages can be detected and determined with ease. Nos. 19, 20, 21, and 22 of the same table show the application to other materials, the results on the titaniferous magnetite being of special interest.

If the expected content of vanadium in a sample is not known accurately enough for adding the necessary excess of phosphoric acid, two or more precipitations may be necessary.

We have found the arrangement shown in Fig. 1 useful for handling the concentrated sulphuric acid; it is much more convenient to use than a reagent bottle. It stands on a large sheet of glass. Also, the funnel with glass stopper (Fig. 2) is useful but not necessary. It is made by sealing a carbon filter to the inlet tube of a thick-walled glass wash bottle, the latter being used as a suction filter flask. If rubber stoppers are used, they should be good sound ones, so that pieces of rubber can not drop into the concentrated sulphuric acid solutions.

[20] Bureau Standards Circular No. 26, 2d ed., p. 10.

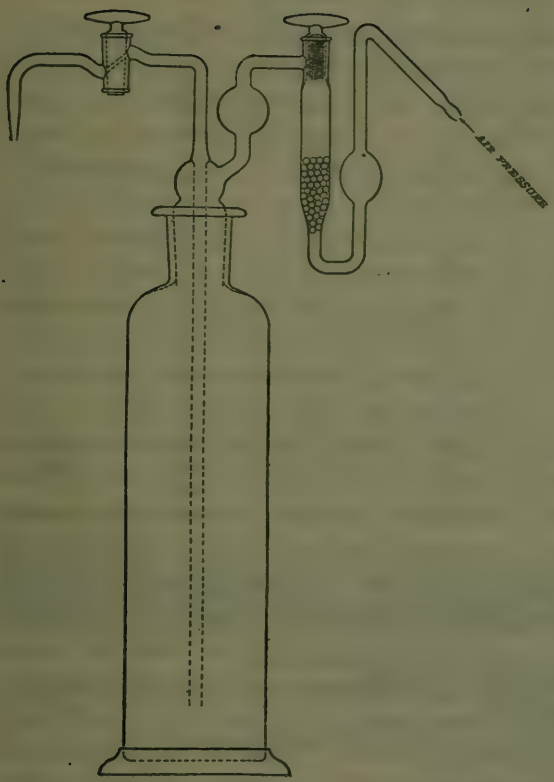

Fig. 1

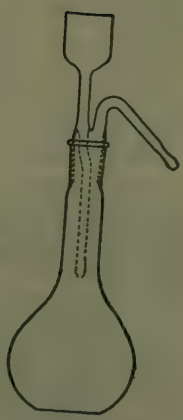

Fig. 2

TABLE II

Results Obtained by the Peroxide Reduction Method [21]

No.	Amount	Cr present	P added	V present	V found	V_2O_3 found
	g	mg	mg	mg	mg	Per cent
[22] 1	1	45	12	1.11	1.17	.....
2	1	180	20	1.92	1.91	.....
3	1	135	35	3.19	3.26	.....
4	1	90	45	4.52	4.60	.....
5	1	45	60	6.38	6.49	.....
6	1	225	100	10.64	10.73	.....
[23] 7	1	50	10	1.02	1.16	.....
8	1	100	25	2.54	2.58	.....
9	1	150	40	4.06	4.15	.....
10	1	200	50	5.08	5.07	.....
11	1	250	60	6.08	6.18	.....
12	1	50	80	8.13	8.40	.....
13	1	100	90	9.12	9.42	.....
14	1	150	100	10.15	10.22	.....
[24] 15	5	.....	19	.....	0.995	.....
16	20	.....	20	1.00	1.02	.....
17	20	.....	19	1.11	1.24	.....
[25] 18	1	.....	25	2.66	2.75	.....
[26] 19	2	.....	19	.....	1.07	0.078
[27] 20	10	.....	39	.....	3.41	0.05
[28] 21	10	.....	19	.....	0.66	0.01
[29] 22	10	.....	19	.....	0.81	0.012

[21] Except as otherwise indicated, the solutions used for these determinations were made by adding chromium and vanadium to the nitric-acid solution of a vanadium and chromium-free steel, in the proportions indicated in the table. The vanadium was added from an ammonium vanadate solution, which was standardized by reducing with sulphur dioxide and titrating against permanganate; the chromium was added from a chrome-alum solution, the chromium content being calculated from the amount of salt weighed out.

[22] Nos. 1 to 6, and 15 to 22, inclusive, reduced with magnesium peroxide.

[23] Nos. 7 to 14, inclusive, reduced with hydrogen peroxide.

[24] No. 15. Bureau of Standards. Chrome-Tungsten Steel Standard (in preparation) V found=0.02 per cent (not determined by any other method).

[25] No. 18 contained 23 mg of titanium as titanium sulphate.

[26] No. 19. Bureau of Standards Magnetite Ore. No. 29. B. S. Chemist's value 0.075% V_2O_3.

[27] No. 20. Bureau of Standards Manganese Ore, No. 25.

[28] No. 21. Bureau of Standards Sibley Ore, No. 27.

[29] No. 22. Bureau of Standards Crescent Ore. No 26.

The largest amount of vanadium determined in Table II (10.64 mg, or about 1 per cent on a 1-g sample) gives about as large a volume of precipitate as it is convenient to handle. We have precipitated and determined accurately as much as 27 mg of vanadium, using the 10 to 1 ratio of phosphorus, but the manipulation in such cases becomes inconvenient. This is about the only serious limitation placed on the method, making it necessary when dealing with large amounts of vanadium to precipitate from an aliquot corre-

sponding to a relatively small sample. For steels, alloys, ores, rocks, etc., containing from traces up to 5 or 6 per cent of vanadium, the method, we believe, can be used wherever phosphorus can be precipitated as phosphomolybdate from solutions of these materials.

7. NOTES AND PRECAUTIONS

The presence of vanadium in the phosphomolybdate precipitate is shown by the yellow to orange color of the cold concentrated sulphuric acid solution of the precipitate, 0.05 mg vanadium showing a perceptible color in a volume of 25 cc.

In carrying out the peroxide reductions it is necessary to use a flask instead of an open dish or beaker. If the latter is used, there is reduction of the molybdenum where the strong acid solution "creeps" up along the sides of the vessel, the reduction showing by the development of an intense blue coloration.

If after the addition of peroxide and subsequent heating, the vanadium is not reduced, it is probably due to traces of nitric acid in the solution, which may be removed by further fuming; the treatment with peroxide should then be repeated. In this connection, we may note that nitrous fumes readily oxidize tetravalent vanadium, and hence the reductions should be carried out in an atmosphere free from such fumes.

After the reduction it is advisable to cover the flask with a watch glass while the solution is cooling, in order to prevent accidental introduction of organic matter.

If the final titration is carried out in acid of greater concentration than one to two by volume, the end point is rendered uncertain, because of the deep yellow color which the pentavalent vanadium, formed during the titration, gives with strong sulphuric acid. We recommend a dilution of one to five, in which the end point is very sharp.

The time required for making a determination is worthy of note. Working with vanadium steel, the sample was weighed out, dissolved, and precipitated in 10 minutes, the precipitate washed and dissolved in sulphuric acid in 9 minutes more, while the reduction and titration required a further 12 minutes, giving the completed determination in approximately one-half hour. By operating on

a large number of samples at one time, the determination can be made as rapid as, if not more rapid, than that of phosphorus in steels. We have frequently completed 20 determinations in less than 7 hours, even while giving much attention to uncompleted details. With these worked out, the method should allow the completion of twice as many determinations in a day.

Manganese ores are readily decomposed with hydrogen peroxide in the presence of nitric acid. This solution is very well adapted for the determination of vanadium. The insoluble should also be tested for vanadium.

When precipitating vanadium from a solution containing hydrochloric acid and, in general, when the volume of the solution is very great, we recommend the addition of 10 g of solid ammonium nitrate for every 100 cc of solution.

8. SUMMARY

1. It was found that vanadic acid may be quantitatively precipitated by ammonium phosphomolybdate.

2. The vanadium-bearing phosphomolybdate shows different solubility relations compared with the normal phosphomolybdate with respect to the usual washing solutions used in determining phosphorus.

3. Conditions are given for quantitatively precipitating vanadic acid when in solution alone, or accompanied by a variety of other elements, by means of ammonium phosphomolybdate.

4. In order to determine quantitatively the vanadic acid so precipitated, (a) the possibility of freeing it from accompanying molybdic acid was investigated; (b) conditions for reducing it without reducing the associated molybdic acid were developed; and (c) a method for reducing it by hydrogen (and other) peroxides and titrating it against permanganate was elaborated.

5. Method (c) was applied to a variety of steels, to iron ores, manganese ores, and to synthetic mixtures, in all of which the vanadium was determined with great accuracy.

WASHINGTON, October 26, 1911.

DEPARTMENT OF COMMERCE AND LABOR

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 9

DENSITY AND THERMAL EXPANSION OF LINSEED OIL AND TURPENTINE

(INCLUDING CONVERSION TABLES OF POUNDS TO GALLONS AND GALLONS TO POUNDS)

BY

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Bureau of Standards

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By H. W. Bearce

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INTRODUCTION

An investigation of the density and thermal expansion of linseed oil and turpentine was undertaken in response to a demand from those engaged in the manufacture, distribution, and use

of these substances, for more complete knowledge of their physical constants as an aid in setting up standards of purity. There appears also to be a considerable demand for tables showing the change of density of these materials with change of temperature, and for conversion tables for changing from pounds to gallons and from gallons to pounds. The need for such conversion tables arises from the fact that both linseed oil and turpentine are often bought by weight and sold by measure and vice versa. Tables based upon the results of this investigation have been prepared and are published at the end of this paper.

MATERIAL USED

The samples of linseed oils used in this investigation were secured from the American Society for Testing Materials, through the courtesy of Mr. S. S. Voorhees, a member of the special committee appointed by that society to carry out an investigation of commercial linseed oils. The origin and history of the samples used was as follows:

Samples Nos. 1 to 4, inclusive, were from the same lots of oil as that reported on at the 1909 meeting of the American Society for Testing Materials. In addition to the bottles filled at the time the samples were taken (February, 1909), two 5-gallon cans of each sample were filled and sealed for future examination, to determine the effect of aging. The cans were nearly full and were hermetically sealed. One of these cans for each sample was opened February 23, 1911, and the oil thoroughly mixed and bottled.

Sample No. 5 was obtained from a 5-gallon can taken on June 15, 1910, at the American Linseed Co.'s South Chicago mill. Can opened and bottled March 1, 1911; oil made from North American seed.

Sample No. 6 was obtained July 21, 1910, at Archer-Daniels Linseed Co.'s Minneapolis mill. Oil bottled March 1, 1911; oil made from North American seed.

Samples Nos. 7 to 16, inclusive, were taken with the idea of observing the variation in the constants of pure raw linseed oil, as affected by the origin and age of the seed from which they were made. The samples were received in sealed cans by the com-

mittee and were opened and bottled February 18, 1911. All samples except No. 16 were from North American seed.

Sample No. 7 was taken at Archer-Daniels Linseed Co.'s Minneapolis mill about September 30, 1910.

Sample No. 8 was taken at Archer-Daniels Linseed Co.'s Minneapolis mill October 27, 1910.

Sample No. 9 was taken at Archer-Daniels Linseed Co.'s Minneapolis mill about November 30, 1910.

Sample No. 10 was taken at Archer-Daniels Linseed Co.'s mill about December 31, 1910.

Sample No. 11 was taken at Hirst & Begley's Chicago mill, September 30, 1910, largely from Southwestern seed.

Sample No. 12 was taken at Hirst & Begley's Chicago mill October 31, 1910, from Northwestern seed.

Sample No. 13 was taken at Hirst & Begley's Chicago mill November 29, 1910, from Southwestern seed.

Sample No. 14 was taken at Hirst & Begley's Chicago mill December 29, 1910, from Northwestern seed.

Sample No. 15 was taken at Hirst & Begley's Chicago mill January 31, 1911, from Northwestern seed.

Sample No. 16 was taken at the National Lead Co.'s Atlantic mill February 24, 1911, from Argentine seed.

The samples of turpentine used in this investigation, while fewer in number than the samples of linseed oil, may, it is believed, be considered fairly representative of the articles of commerce known as "spirits of turpentine," "turpentine," and, in the paint trade, as "turps." The origin of the various samples, as far as known, is as follows:

Sample No. 1 was purchased under Government contract as "turpentine."

Samples Nos. 2 and 3 were purchased in the retail trade of Washington, D. C., as "turpentine."

Samples Nos. 7 and 8 were furnished by the Geo. L. Morton Co., of Wilmington, N. C.—No. 7 as pure gum spirits from first year's run (virgin dip) and No. 8 as pure gum spirits from later run (yellow dip).

Sample No. 12 was furnished by the Hendrics Turpentine Co., of Tampa, Fla., as pure gum spirits distilled from second year's run without use of steam.

In addition to the above samples of gum turpentine, several samples of wood turpentine and other products of the distillation of wood were secured and tested. The samples were as follows:

Sample No. 4, furnished by the Waycross Power & Light Co., Waycross, Ga., was obtained by the distillation of waste wood by the steam process.

Samples Nos. 9, 10, and 11, furnished by F. T. Sutherland & Co., of Jacksonville, Fla., were obtained from the distillation of waste wood by the steam process. No. 11 was a part of the last fraction of the distillation in which No. 10 was secured. No. 11 is known as "oil" of turpentine.

Samples Nos. 5 and 6, furnished by the Spiritine Chemical Co., of Wilmington, N. C., were obtained by destructive distillation of waste wood.

All of the above samples, except Nos. 1, 2, and 3, were secured direct from the producers, most of them being delivered at the place of production to Mr. M. H. Stillman of this Bureau.

The 16 samples of linseed oil reported on in this paper, being taken as they were at various times under ordinary working conditions at several of the more important mills of this country, are, it is believed, thoroughly representative of the oil obtained from North American seed. The one sample examined from imported seed was not found to differ essentially from those obtained from North American seed. It is hoped that at some future time the work may be extended to embrace oil made from seed imported from all other important seed-producing countries.

The number of samples of turpentine reported on in this paper is undoubtedly too small to base general conclusions upon, but at the same time it is sufficient to indicate some of the more important facts. It is hoped that the work on turpentine also may be continued with a greater number of samples of known origin and purity.

DESCRIPTION OF EXPERIMENTAL WORK

METHOD OF DETERMINATION OF DENSITY

After obtaining the various samples of linseed oil and turpentine the density of each sample was determined at 10°, 20°, 30°, and 40° C by the method of hydrostatic weighing; that is, by weighing in the sample a sinker of known mass and volume.

The apparatus used in making the density determinations was devised by Mr. N. S. Osborne, formerly of this bureau, and used by him in his work on the density and thermal expansion of ethyl alcohol. A complete description of the apparatus may be found in the publication of that work.

DESCRIPTION OF APPARATUS

The arrangement of apparatus is as follows:

The sample under investigation, and the sinker, are placed in a tube having a length of about 50 cm and a diameter of 2 cm, and surrounded by a temperature bath kept in constant circulation by a small propeller. This inner bath is surrounded by a second bath, which is also kept in constant circulation and whose temperature can be maintained constant or varied at will over a range of 10° to 40° C, the temperature regulation being accomplished by an electric heating coil and a copper coil through which refrigerating brine may be passed. These coils, together with a thermostat, may be so adjusted that any desired temperature between 10° and 40° C is automatically maintained.

The outside containing vessel for the various tubes and baths is a large, unsilvered Dewar cylinder, provided with a brass cap suitable for supporting the inner parts of the apparatus. The cylinder is mounted in a vertical position and covered with a layer of nickeled paper through which windows are cut to permit observations to be made.

The temperature is read on two mercurial thermometers suspended in water in a tube placed symmetrically with that containing the sample whose density is to be measured. The thermometers are so mounted on a movable cap that by its rotation they may be successively brought into position for reading. They are

read by the aid of a long-focus microscope so mounted as to be movable vertically. The object of placing the thermometers in a tube instead of directly in contact with the water of the inner circulating bath is to eliminate, as far as possible, errors due to temperature lag within the densimeter tube. Since the sample under test is separated from the circulating bath by the densimeter tube the thermometers should be separated from it by a similar tube in order that when a constant temperature is indicated by them the same constant temperature shall obtain within the densimeter tube.

The thermometers were used repeatedly over the same temperature range, and from previous experience with the same thermometers over the same range it was thought unnecessary to take ice-point readings after each reading of the thermometers. Ice-point readings were, however, taken occasionally throughout the work and these, together with an extended series obtained earlier in the year, were found to be sufficiently concordant to warrant their use in fixing the corrections to be applied at the various temperatures.

THERMOMETERS

The thermometers used were: B. S. No. 4653, made by Tonnelot in 1888 of Verre dur glass; B. S. No. 2040, by Haak in 1906, of Jena 16^{III} glass; B. S. No. 264, by Richter in 1902, of Jena 16^{III} glass. All thermometers were graduated to 0° 1 C.

SINKER

The sinker used was of Jena 16^{III} glass, ballasted with mercury; its volume, used in making the density determinations was calculated from its weight in vacuo and its apparent weight in twice distilled water at 4°, 10°, 20°, 30°, and 40° C, using Chappuis's values for the density of water. The equation

$$V_t = V_x + \alpha(t-x) + \beta(t-x)^2$$

was assumed to represent sufficiently well the expansion of the sinker, and the values of V_x, α, and β, obtained by making a least squares reduction of the observations, were:

$$V_x = V_{24} = 47.7174 \text{ cc}$$

$$\alpha = 0.001\ 100\ 1$$

$$\beta = 0.000\ 000\ 973\ 4$$

Therefore $V_t = 47.7174 + 0.001\ 100\ 1(t-24) + 0.000\ 000\ 973\ 4\ (t-24)^2$ from which the calculated volumes are as follows:

Temperature	Volume
10° C	47.7022 cc
20° C	47.7130 cc
30° C	47.7240 cc
40° C	47.7352 cc

The sinker is suspended by a hook from a small secondary sinker attached to a wire let down from one pan of the balance. The secondary sinker has a mass sufficient to keep the suspension wire straight and in its proper position, and is always immersed in the liquid, whether the large sinker (of known mass and volume) is attached or not.

At the point where the suspension wire passes through the surface of the liquid it has a diameter of 0.3 mm and is covered with a layer of unpolished gold by electro deposition. In the case of liquids which imperfectly wet the suspension, this roughening of the surface is essential, but with oil and turpentine it was probably unnecessary.

BALANCE, WEIGHTS, AND METHOD OF WEIGHING

All weighings were made by the method of substitution; that is, a constant mass was kept on one pan of the balance and the weighings made on the other, sufficient weights being placed on the pan to secure equilibrium, first with the sinker attached and then detached. The weighings were made on a Rueprecht analytical balance (B. S. No. 5156) having the capacity of 200 grams and a sensibility of 0.08 mg per division when undamped. When the immersed sinker was attached the sensibility was greatly reduced, especially in the case of linseed oil at the lower temperatures, owing to the increased viscosity of the oil. At the higher temperatures weighings could be made to a few tenths of a milligram, but at 10° difficulty was experienced in weighing closer than from 1 to 2 mg.

Of the weights used, those of less than 1 g were a special set provided with the balance, and were manipulated by keys on the outside of the balance without opening the case. Those between 1 g and 100 g were platinum plated brass weights (B. S. No. 5157).

These weights are used only for special purposes and were recalibrated a few months before the beginning of this work, and the maximum error of any possible combination of weights was found to be so small in comparison with accidental errors as to be negligible.

All weighings were reduced to vacuo by means of a special device originally designed for use in correcting weighings of water in the test of volumetric apparatus. This apparatus consists of a glass bulb of such a volume that, when suspended from one arm of a balance and counterpoised against a brass weight of equal mass, the number of milligrams that must be added to the pan from which the bulb is suspended to secure equilibrium is equal to the air buoyancy on a liter of water weighed against brass weights. This buoyancy constant when divided by 881.3 gives the air density. (881.3 is the difference in volume between the brass weights and the glass bulb).

METHOD OF PROCEDURE

In making the density determinations the method of procedure was as follows:

The water in the outside circulating bath was brought to the desired temperature and, before observations were begun, sufficient time was allowed to elapse for the apparatus to reach the steady state. When the thermometers in the inner tube indicated a constant temperature it was assumed that the liquid in the densimeter tube was at the same constant temperature and observations were begun. First, a weighing was made with the sinker suspended in the sample, then the temperature was observed on each of two thermometers; next, a weighing was made with the sinker off, then a second with the sinker on, and after that a second observation of temperature. The temperature was then changed to the next point of the series and here the same order was followed.

CALCULATION OF RESULTS

After completing the observations at the four temperatures 10°, 20°, 30,° and 40° C, the density at each temperature was calculated by means of the equation

$$D_t = \frac{W - \frac{(w - w_1) + (w - w_2)}{2}\left(1 - \frac{\rho}{8.4}\right)}{V_t}$$

in which D_t = density[1] of sample at the temperature t

W = weight of sinker in vacuo
w = weighing with sinker off
w_1 & w_2 = weighings with sinker on
ρ = air density
8.4 = assumed density of brass weights
V_t = volume of sinker at temperature t.

After calculating the density of a sample at 10°, 20°, 30°, and 40° C, it was assumed that the rate of expansion could be represented by the equation

$$D_t = D_x + \alpha(t - x) + \beta(t - x)^2$$

and a least squares reduction was applied to the observed densities in order to find D_x, α, and β, and the most probable value of the density at each temperature.

The observations and reductions of an average sample of linseed oil are given on pages 16 and 17, and following that a summary of the 16 samples of linseed oil arranged in the increasing order of their densities.

DISCUSSION OF RESULTS

It will be seen from the tabulated results that the coefficient of expansion of linseed oil, as determined from the 16 samples tested, varies over rather narrow limits; for example, at 25° C the change of density per degree lies between 0.000 682 and 0.000 687, the mean of the 16 samples being 0.000 684 7. It will be seen also that the rate of change of density is, in general, greater at the lower than at the higher temperatures. Sample No. 9, the only exception, contained a very large amount of suspended matter which was no doubt responsible for the difference observed. It further appears from the tabulated results that the coefficient of expansion

[1] Throughout this paper the term "density" is used to denote the mass of the liquid per unit volume, expressed in grams per milliliter. The densities are, therefore, numerically equal to specific gravities referred to water at 4° C as unity.

is slightly greater for the heavier than for the lighter oils, the mean of the first half of the series being 0.000 684 2 per degree at 25° and of the last half 0.000 685 2. This fact should not, however, be given great weight, as three samples in the first half fall above and four samples in the last half fall below the mean value.

Following the summary of the results of the linseed oil investigation is given a similar summary of those on gum turpentine, wood turpentine, and "wood spirits." From this table it will be seen that the limits of the density and coefficient of expansion of turpentine, while not so narrow as for linseed oil, still are not wide. The change of density of gum turpentine per degree at 25° C lies between 0.000 810 and 0.000 820, with a mean value of 0.000 817 0. Here again, and more noticeably than in the case of linseed oil, the rate of change of density with change of temperature is greater for the heavier than for the lighter samples, but unlike the oil, the rate of change is in this case greater at the higher than at the lower temperatures.

This investigation has shown that if the density of a sample of linseed oil or turpentine be determined at 25°, its density at any other temperature between 10° and 40° C may be calculated within the limits of ordinary experimental error by use of the general equation

$$D_t = D_{25} + \alpha(t-25) + \beta\,(t-25)^2$$

which, on the substitution of the mean values of α and β, becomes for linseed oil

$$D_t = D_{25} - 0.000\,684\,7\,(t-25) + 0.000\,000\,12\,(t-25)^2$$

and for gum turpentine

$$D_t = D_{25} - 0.000\,817\,0\,(t-25) - 0.000\,000\,09\,(t-25)^2$$

Or the density may be measured at any other convenient temperature and for short temperature intervals the correction factor applied as a single term.

In the tables given at the end of this paper the values for turpentine have been extended somewhat beyond the range of the densities actually measured in this investigation in order to more nearly cover the range found by Veitch and Donk [2] in their recent investigation of a great number of commercial turpentines.

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[2] Bureau of Chemistry, Bull. No. 135, Apr., 1911.

In calculating the turpentine tables the mean value of the rate of change of density with change of temperature has not been used. The greater rate of change of the heavier turpentines has been taken into account by applying to the mean value a correction deduced from the difference between the mean rate of change of the three heaviest and the three lightest samples.

In regard to the accuracy of the results given in this paper, it is believed that in all cases except that of linseed oil at 10° C the density determinations are correct to within three units of the fifth decimal place, and in this case to five units of the fifth place. This corresponds to an accuracy of about 1 part in 30 000, and 1 part in 18 000, respectively. The decreased accuracy is due to the increased viscosity of the oil and the resulting decreased sensibility of the balance.

COMPARISON OF RESULTS WITH PREVIOUS WORK

A comparison of the results of the present investigation with other published results may be of interest. The scarcity of data available and the doubt as to the actual meaning of the term "specific gravity," as ordinarily employed, render such a comparison in many cases impossible. The values given by Allen [3] and by Andès [4] for the coefficient of expansion of linseed oil are, respectively, 0.000 649 and 0.000 63 per degree C. Ennis [5] gives 0.000 45 per degree F. (0.000 81 per degree C). The low value given by Allen may be explained, at least in part, by his assumption that the coefficient of expansion is the same at all temperatures. He measured the density at two widely separated temperatures, and thus obtained the mean rate of change of density between these temperatures. Since the present work has shown that the rate of change is less at the higher than at the lower temperatures, Allen's mean coefficient is too low for ordinary laboratory temperatures. Hurst [6] gives a value of 0.000 65, and Maire [7]

[3] Commercial organic analysis, vol. 1, pt. 1.
[4] Boiled oils, drying oils, etc.
[5] Linseed oil and other seed oils.
[6] Painters' colors, oils, and varnishes.
[7] Modern pigments and their vehicles.

0.000 63, but Maire's application of the coefficient as a temperature correction to the density is in the wrong direction. The most complete and definite results found are those given by Sabin.[8] He gives as the coefficient of expansion of linseed oil between 15°.5 and 28° C, 0.000 692; and between 28° and 100° C 0.000 720 per degree. This value of the coefficient between 15°.5 and 28° C is in better agreement with the results of the present work than any other found, but the increased coefficient at the higher temperatures, reported by Sabin, is not confirmed by this work.

PHYSICAL AND CHEMICAL CONSTANTS OF THE LINSEED OIL SAMPLES EXAMINED

The results given below are the mean values of the independent determinations by seven chemists to whom the samples were submitted by subcommittee E of the American Society for Testing Materials. A detailed report of this committee is published in the 1911 proceedings of that society.

Sample No.	Refractive index at 25° C	Iodine No. (Hanus)	Acid No.	Saponification No.	Unsaponifiable matter	Density at 25° C grams/ml.[9]
1	1.4799	186.9	1.39	190.7	0.96	0.927 56
2	1.4792	183.0	4.38	190.8	0.96	0.925 68
3	1.4793	186.0	2.79	190.2	0.98	0.925 86
4	1.4794	184.1	1.86	190.4	1.04	0.927 06
5	1.4785	179.0	4.54	190.9	0.97	0.924 80
6	1.4782	177.9	2.04	190.6	1.06	0.926 38
7	1.4790	181.4	2.12	191.3	1.08	0.926 88
8	1.4793	183.0	1.49	190.9	1.10	0.926 80
9	1.4793	182.2	1.83	191.2	1.15	0.927 20
10	1.4795	184.2	1.59	191.7	1.06	0.927 30
11	1.4789	179.4	0.97	190.9	1.10	0.925 78
12	1.4792	183.4	0.98	190.4	1.04	0.925 96
13	1.4790	180.7	0.94	191.2	1.12	0.925 34
14	1.4796	187.0	0.99	190.8	1.01	0.926 72
15	1.4796	184.9	1.70	191.3	1.03	0.927 20
16	1.4779	172.4	1.24	190.6	1.05	0.924 99

[8] Technology of paint and varnish.

[9] Determinations by author.

PHYSICAL AND CHEMICAL CONSTANTS OF THE GUM TURPENTINE SAMPLES EXAMINED

Below are given the physical and chemical constants of the six samples of turpentine on which Table IV is based.

Sample No.	Initial distilling temperature, °C	Per cent distilling below—			Per cent polymerization residue	Per cent residue on drying at 105° C	Refractive index at 27° C	Optical rotation at 25° C [10]	Per cent mineral oil	Density at 25° C grams/ml.[11]
		160° C	165° C	170° C						
1.....	156	29	47	64	1.6	21.24	1.4784	+14.4	Less than 5...	0.862 40
2.....	157	28	51	72	1.6	10.12	1.4710	− 7.2	.....do.....	0.859 84
3.....	157	20	83	91	3.2	1.17	1.4671	− 8.6	.....do.....	0.857 19
7.....	156	49	87	94	0.8	1.87	1.4673	+15.9	.....do.....	0.857 66
8.....	155	39	85	93	1.6	1.60	1.4670	+12.7	.....do.....	0.860 32
12.....	154	41	89	94	2.4	1.03	1.4672	+ 4.3	.....do.....	0.861 66

[10] The optical rotation is calculated by use of the equation

$$\text{Optical rotation} = \frac{\text{angle of rotation}}{\text{length of solution, in cms.} \times \text{density at } 25^\circ \text{ C}}$$

[11] Determinations by author.

In connection with this table it should be stated that, owing to the limited quantities of the several samples, the chemical constants given are, in each case, the results of a single determination only and do not therefore represent the same degree of accuracy as do the corresponding values for linseed oil. No attempt will be made to explain the abnormally high residues on drying at 105° C, and the relatively low percentages distilling below 170° C, of samples Nos. 1 and 2, as the samples were too small for further investigation.

In conclusion, the author would acknowledge his indebtedness to the chemical division of this Bureau for the analysis of the turpentine samples; to Messrs. Nutting and Jackson, also of this Bureau, for determining the refractive index and optical rotation, respectively; and to the American Society for Testing Materials for the samples of linseed oil and for the chemical analysis made by members of that society.

WASHINGTON, D. C., November 1, 1911.

SAMPLE SET OF OBSERVATIONS

Linseed Oil. Sample No. 6. Observations and Calculation of Densities

Date	Temperatures		Corrected temperatures	Balance reading	Apparent weight	Air buoyancy	Corrected weight	Weight of sinker (in vacuo)	Weight of displaced liquid	Volume	D_t	D_t (reduced to integral degrees)
April 13, 1911.....	#2040	#4653				1052						
	−.008	+.091				22°8						
	10.055	9.975	10.047 10.066	38.5045	55.3263	25°2						
12.30 p. m....	10.028	9.972	10.020 10.063	93.8308	55.3263	1042						
				38.5045		.001182						
			10.049		55.3263	−.0078	55.3185	99.9990	44.6805	47.702 18	0.936 655	0.936 689
											+34	(10° C)
	−.003	+.036										
	19.870	19.828	19.867 19.864	38.1802	55.6389							
1.40 p. m.....	19.875	19.848	19.872 19.884	93.8191	55.6401							
				38.1790								
			19.872		55.6395	−.0078	55.6317	99.9990	44.3673	47.712 82	.929 882	.929 794
											−88	(20° C)
	−.005	+.005										
	29.960	29.960	29.955 29.965	37.8496	55.9576							
2.40 p. m.....	29.965	29.962	29.960 29.967	93.8072	55.9586							
				37.8486								
			29.962		55.9581	−.0078	55.9503	99.9990	44.0487	47.723 94	.922 990	.922 964
											−26	(30° C)
	#264											
	−.033											
	39.780		39.747	37.5280	56.2682							
3.25 p. m.....	39.795		39.762	93.7962	56.2688							
				37.5274								
			39.754		56.2685	−.0079	56.2606	99.9990	43.7384	47.734 92	.916 277	.916 109
											−168	(40° C)

NOTE.—In the above column headed "Air buoyancy" 1052 is the observed buoyancy constant, 22°8 C is the temperature at the buoyancy bulb, 25°2 C is the temperature in the balance, 1042 is the buoyancy constant corrected to the temperature of the balance, 0.001 182 is the air density in the balance, 0.0078 g is the buoyancy correction to be applied to the apparent weight.

SAMPLE OF REDUCTION OF OBSERVATIONS

Linseed Oil. Sample No. 6

t	$\frac{(t-t_m)}{C_1}$	C_1^2	$\frac{[C_1^2-(C_1^2)_m]}{C_2}$	C_2^2	D_t	$\frac{[D_t-(D_t)_m]}{N}$	C_1N	C_2N
10	−15	225	100	10 000	0.936 689	+0.010 300	−0.154 50	+1.0300
20	− 5	25	−100	10 000	.929 794	+ .003 405	− .017 02	− .3405
30	5	25	−100	10 000	.922 964	− .003 425	− .017 12	+ .3425
40	15	225	100	10 000	.916 109	− .010 280	− .154 20	−1.0280
25		500		40 000	.926 389		− .342 84	+ .0040

$$500\alpha = -0.342\ 84$$
$$\alpha = -.000\ 685\ 7$$
$$40\ 000\beta = +.004$$
$$\beta = +.000\ 000\ 1$$

$D_x + 125\beta = D_m$
$D_x = D_{25} = 0.926\ 389 - 0.000\ 012$
$D_{25} = 0.926\ 377$
$D_t = D_{25} + \alpha(t-25) + \beta(t-25)^2$
$D_t = 0.926\ 377 - 0.000\ 685\ 7(t-25) + 0.000\ 000\ 1(t-25)^2$

t	t−25	$(t-25)^2$	$\alpha(t-25)$	$\beta(t-25)^2$	Calculated D_t	Observed D_t	Obs.—cal.
10	−15	225	+0.010 286	+0.000 022	0.936 68	0.936 69	1
20	− 5	25	+ .003 428	+ .000 002	.929 81	.929 79	−2
30	5	25	− .003 428	+ .000 002	.922 95	.922 96	1
40	15	225	− .010 286	+ .000 022	.916 11	.916 11	0

SUMMARIES OF RESULTS

Density and Thermal Expansion of Linseed Oil at Temperatures Between 10° and 40° C

Sample No.	$D_{4°C}^{10°C}$	$D_{4°C}^{20°C}$	$D_{4°C}^{30°C}$	$D_{4°C}^{40°C}$	$D_{4°C}^{25°C}$	$\alpha \times 10^7$	$\beta \times 10^9$
5	0.935 13	0.928 23	0.921 39	0.914 60	0.924 80	−6844	+262
16	.935 26	.928 41	.921 58	.914 75	.924 99	−6836	+ 50
13	.935 61	.928 75	.921 93	.915 14	.925 34	−6823	+192
2	.935 98	.929 11	.922 26	.915 43	.925 68	−6851	+ 90
11	.936 06	.929 20	.922 35	.915 52	.925 78	−6848	+ 58
3	.936 14	.929 28	.922 44	.915 61	.925 86	−6843	+ 90
12	.936 24	.929 38	.922 55	.915 73	.925 96	−6838	+ 95
6	.936 68	.929 81	.922 95	.916 11	.926 38	−6857	+100
14	.937 04	.930 16	.923 29	.916 42	.926 72	−6875	+ 38
8	.937 10	.930 22	.923 38	.916 57	.926 80	−6843	+168
7	.937 16	.930 31	.923 47	.916 64	.926 88	−6840	+ 78
4	.937 38	.930 49	.923 65	.916 86	.927 06	−6842	+240
9	.937 46	.930 62	.923 77	.916 91	.927 20	−6850	− 88
15	.937 55	.930 63	.923 78	.916 99	.927 20	−6852	+320
10	.937 61	.930 73	.923 89	.917 07	.927 30	−6844	+155
1	.937 89	.931 00	.924 13	.917 27	.927 56	−6873	+ 78
Mean					.926 34	−6847	+120

(1) $$D_t = D_{25} + \alpha(t-25) + \beta(t-25)^2$$

Taking for α and β the mean values of the 16 samples the general equation becomes $D_t = D_{25} - 0.000\ 6847(t-25) + 0.000\ 000\ 12(t-25)^2$. If it is desired to reduce the expansion to a single term for use over a short temperature range, this may be done by differentiating the general equation and combining α and β into a single term, α^1, which will be different for different temperatures.

$$D_t = D_{25} + \alpha(t-25) + \beta(t-25)^2$$

(2) $$\frac{dD_t}{dt} = \alpha + 2\beta(t-25) = \alpha^1$$

Substituting for t the values 10, 15, 20, 25, 30, 35, and 40, gives for the rate of change of density at the different temperatures the following values:

Temperature °C	Change per °C
10	0.000 688 3
15	.000 687 1
20	.000 685 9
25	.000 684 7
30	.000 683 5
35	.000 682 3
40	.000 681 1

Density and Thermal Expansion of Turpentine at Temperatures Between 10° and 40° C

Sample No.	$D\frac{10°}{4°}c$	$D\frac{20°}{4°}c$	$D\frac{30°}{4°}c$	$D\frac{40°}{4°}c$	$D\frac{25°}{4°}c$	$\alpha \times 10^7$	$\beta \times 10^9$	Refractive index at 27 °C	Optical rotation at 25 C°	Remarks
									°	
3	0.869 32	0.861 24	0.853 14	0.845 00	0.857 19	−8104	−150	1.4671	− 8.6	Group I, gum turpentines.
7	.869 88	.861 74	.853 57	.845 39	.857 66	−8165	− 95	1.4673	+15.9	
2	.872 11	.863 94	.855 74	.847 52	.859 84	−8195	−105	1.4710	− 7.2	
8	.872 56	.864 40	.856 23	.848 04	.860 32	−8174	− 55	1.4670	+12.7	
12	.873 93	.865 76	.857 56	.849 33	.861 66	−8198	−148	1.4672	+ 4.3	
1	.874 68	.866 49	.858 31	.850 12	.862 40	−8186	− 8	1.4784	+14.4	
Mean						−8170	− 94			
9	.869 88	.861 65	.853 41	.845 16	.857 53	−8242	− 55	1.4636	+22.9	Group II, wood turpentine steam distilled.
10	.870 24	.862 05	.853 84	.845 59	.857 95	−8214	−160	1.4656	+17.7	
4	.872 29	.864 06	.855 71	.847 24	.859 90	−8350	−580	1.4648	+26.3	
Mean						−8269	−265			
5	.873 80	.864 56	.855 47	.846 26	.860 06	−9181	−130	1.4594	+ 4.7	Group III, wood "spirits" destructively distilled.
6	.876 06	.866 93	.857 75	.848 52	.862 35	−9181	−258	1.4613	+ 4.7	
11	.955 18	.947 28	.939 30	.931 23	.943 30	−7986	−428	1.4789	0.0	"Oil" of turpentine.

The results obtained from the six samples of gum turpentine shown in Group I were used in the calculation of Table IV for determining the density of turpentine at various temperatures.

If the general equation $D_t = D_{25} + \alpha(t-25) + \beta(t-25)^2$ be differentiated and the mean values of α and β substituted in the first derivative the change of density per degree at different temperatures is seen to be as shown below.

$D_t = D_{25} + \alpha (t-25) + \beta (t-25)^2$

$\frac{d D_t}{dt} = \alpha + 2\beta (t-25) =$ change of density per degree $= \alpha^1$

t	α^1
10	.000 814 2
15	815 1
20	816 1
25	817 0
30	817 9
35	818 9
40	819 8

In calculating Table IV these values of α^1 were taken as the rate of change of density of turpentine having a density of 0.8640 at 20° C (this being the mean of the six samples from which α^1 was derived). For turpentine having a density at 20° either greater or less than 0.8640 α^1 was calculated from mean $D\frac{20°}{4°}$ and mean α^1 of the three lightest samples, and mean $\frac{D20°}{4°}$ and mean α^1 of the three heaviest samples.

TABLES OF DENSITY, WEIGHT, AND VOLUME

TABLE I

Density of Linseed Oil at Temperatures from 10° to 40° C from its Density at 20° C

	Density at 20° C (in grams per milliliter)						
	0.9260	0.9270	0.9280	0.9290	0.9300	0.9310	0.9320
Required temperature	Density at required temperature						
°C							
10	0.9329	0.9339	0.9349	0.9359	0.9369	0.9379	0.9389
11	.9322	.9332	.9342	.9352	.9362	.9372	.9382
12	.9315	.9325	.9335	.9345	.9355	.9365	.9375
13	.9308	.9318	.9328	.9338	.9348	.9358	.9368
14	.9301	.9311	.9321	.9331	.9341	.9351	.9361
15	.9294	.9304	.9314	.9324	.9334	.9344	.9354
16	.9288	.9298	.9308	.9318	.9328	.9338	.9348
17	.9281	.9291	.9301	.9311	.9321	.9331	.9341
18	.9274	.9284	.9294	.9304	.9314	.9324	.9334
19	.9267	.9277	.9287	.9297	.9307	.9317	.9327
20	.9260	.9270	.9280	.9290	.9300	.9310	.9320
21	.9253	.9263	.9273	.9283	.9293	.9303	.9313
22	.9246	.9256	.9266	.9276	.9286	.9296	.9306
23	.9239	.9249	.9259	.9269	.9279	.9289	.9299
24	.9233	.9243	.9253	.9263	.9273	.9283	.9293
25	.9226	.9236	.9246	.9256	.9266	.9276	.9286
26	.9219	.9229	.9239	.9249	.9259	.9269	.9279
27	.9212	.9222	.9232	.9242	.9252	.9262	.9272
28	.9205	.9215	.9225	.9235	.9245	.9255	.9265
29	.9198	.9208	.9218	.9228	.9238	.9248	.9258
30	.9192	.9202	.9212	.9222	.9232	.9242	.9252
31	.9185	.9195	.9205	.9215	.9225	.9235	.9245
32	.9178	.9188	.9198	.9208	.9218	.9228	.9238
33	.9171	.9181	.9191	.9201	.9211	.9221	.9231
34	.9164	.9174	.9184	.9194	.9204	.9214	.9224
35	.9157	.9167	.9177	.9187	.9197	.9207	.9217
36	.9150	.9160	.9170	.9180	.9190	.9200	.9210
37	.9144	.9154	.9164	.9174	.9184	.9194	.9204
38	.9137	.9147	.9157	.9167	.9177	.9187	.9197
39	.9130	.9140	.9150	.9160	.9170	.9180	.9190
40	.9123	.9133	.9143	.9153	.9163	.9173	.9183

TABLE II

Weights (in Pounds) of Various Volumes (in Gallons) of Linseed Oil

	Density of Oil (in grams per milliliter)															
	0.9190	0.9200	0.9210	0.9220	0.9230	0.9240	0.9250	0.9260	0.9270	0.9280	0.9290	0.9300	0.9310	0.9320	0.9330	0.9340	0.9350
Gallons	**Weight of Oil (in pounds)**																
1	7.66	7.67	7.68	7.69	7.69	7.70	7.71	7.72	7.73	7.74	7.74	7.75	7.76	7.77	7.78	7.79	7.79
2	15.32	15.34	15.36	15.37	15.39	15.40	15.42	15.44	15.46	15.47	15.49	15.50	15.52	15.54	15.56	15.57	15.59
3	22.98	23.01	23.03	23.06	23.08	23.11	23.13	23.16	23.18	23.21	23.23	23.26	23.28	23.31	23.33	23.36	23.38
4	30.64	30.68	30.71	30.74	30.78	30.81	30.84	30.88	30.91	30.94	30.98	31.01	31.04	31.08	31.11	31.14	31.18
5	38.30	38.34	38.39	38.43	38.47	38.51	38.55	38.60	38.64	38.68	38.72	38.76	38.80	38.85	38.89	38.93	38.97
6	45.96	46.01	46.06	46.11	46.16	46.21	46.26	46.31	46.36	46.41	46.46	46.51	46.56	46.62	46.66	46.71	46.76
7	53.62	53.68	53.74	53.80	53.86	53.92	53.97	54.03	54.09	54.15	54.21	54.27	54.32	54.38	54.44	54.50	54.56
8	61.28	61.35	61.42	61.48	61.55	61.62	61.68	61.75	61.82	61.89	61.95	62.02	62.09	62.15	62.22	62.29	62.35
9	68.94	69.02	69.10	69.17	69.24	69.32	69.40	69.47	69.55	69.62	69.70	69.77	69.85	69.92	70.00	70.07	70.15
10	76.61	76.69	76.77	76.86	76.94	77.02	77.11	77.19	77.27	77.36	77.44	77.52	77.61	77.69	77.77	77.86	77.94
20	153.21	153.38	153.55	153.71	153.88	154.05	154.21	154.38	154.55	154.71	154.88	155.05	155.21	155.38	155.55	155.71	155.88
30	229.82	230.07	230.32	230.57	230.82	231.07	231.32	231.57	231.82	232.07	232.32	232.57	232.82	233.07	233.32	233.57	233.82
40	306.42	306.76	307.09	307.42	307.76	308.09	308.42	308.76	309.09	309.43	309.76	310.10	310.43	310.76	311.10	311.43	311.76
50	383.03	383.44	383.86	384.28	384.70	385.12	385.53	385.95	386.36	386.78	387.20	387.62	388.04	388.46	388.87	389.28	389.70
60	459.64	460.13	460.64	461.14	461.63	462.14	462.64	463.14	463.64	464.14	464.64	465.14	465.64	466.15	466.64	467.14	467.65
70	536.24	536.82	537.41	537.99	538.57	539.16	539.74	540.83	540.91	541.50	542.08	542.67	543.25	543.84	544.42	545.00	545.59
80	612.85	613.51	614.18	614.85	615.51	616.18	616.85	617.52	618.18	618.86	619.52	620.19	620.86	621.53	622.19	622.86	623.53
90	689.45	690.20	690.96	691.70	692.45	693.21	693.95	694.71	695.46	696.21	696.96	697.72	698.46	699.22	699.97	700.71	701.47
100	766.1	766.9	767.7	768.6	769.4	770.2	771.1	771.9	772.7	773.6	774.4	775.2	776.1	776.9	777.7	778.6	779.4
200	1532.1	1533.8	1535.5	1537.1	1538.8	1540.5	1542.1	1543.8	1545.5	1547.1	1548.8	1550.5	1552.1	1553.8	1555.5	1557.1	1558.8
300	2298.2	2300.7	2303.2	2305.7	2308.2	2310.7	2313.2	2315.7	2318.2	2320.7	2323.2	2325.7	2328.2	2330.7	2333.2	2335.7	2338.2
400	3064.2	3067.6	3070.9	3074.2	3077.6	3080.9	3084.2	3087.6	3090.9	3094.3	3097.6	3101.0	3104.3	3107.6	3111.0	3114.3	3117.6
500	3830.3	3834.4	3838.6	3842.8	3847.0	3851.2	3855.3	5859.5	3863.6	3867.8	3872.0	3876.2	3880.4	3884.6	3888.7	3892.8	3897.0
600	4596.4	4601.3	4606.4	4611.4	4616.3	4621.4	4626.4	4631.4	4636.4	4641.4	4646.4	4651.4	4656.4	4661.5	4666.4	4671.4	4676.5
700	5362.4	5368.2	5374.1	5379.9	5385.7	5391.6	5397.4	5403.3	5409.1	5415.0	5420.8	5426.7	5432.5	5438.4	5444.2	5450.0	5455.9
800	6128.5	6135.1	6141.8	6148.5	6155.1	6161.8	6168.5	6175.2	6181.8	6188.6	6195.2	6201.9	6208.6	6215.3	6221.9	6228.6	6235.3
900	6894.5	6902.0	6909.6	6917.0	6924.5	6932.1	6939.5	6947.1	6954.6	6962.1	6969.6	6977.2	6984.6	6992.2	6999.7	7007.1	7014.7
1000	7661	7669	7677	7686	7694	7702	7711	7719	7727	7736	7744	7752	7761	7769	7777	7786	7794
2000	15321	15338	15355	15371	15388	15405	15421	15438	15455	15471	15488	15505	15521	15538	15555	15571	15588
3000	22982	23007	23032	23057	23082	23107	23132	23157	23182	23207	23232	23257	23282	23307	23332	23357	28382
4000	30642	30676	30709	30742	30776	30809	30842	30876	30909	30943	30976	31010	31043	31076	31110	31143	31176
5000	38303	38344	38386	38428	38470	38512	38553	38595	38636	38678	38720	38762	38804	38846	38887	38928	38970
6000	45964	46013	46064	46114	46163	46214	46264	46314	46364	46414	46464	46514	46564	46615	46664	46714	46765
7000	53624	53682	53741	53799	53857	53916	53974	54033	54091	54150	54208	54267	54325	54384	54442	54500	54559
8000	61285	61351	61418	61485	61551	61618	61685	61752	61818	61886	61952	62019	62086	62153	62219	62286	62353
9000	68945	69020	69096	69170	69245	69321	69395	69471	69546	69621	69696	69772	69846	69922	69997	70071	70147
10000	76606	76689	76773	76856	76939	77023	77106	77190	77273	77357	77440	77524	77607	77691	77774	77857	77941

NOTE.—These tables are calculated on the assumption that the densities are measured at 20° and that the weighings are made at the same temperature in air of 50 per cent humidity, and at a pressure of 760 mm. of mercury against brass weights having a density of 8.4. The tables may be used, without appreciable error, for determinations at all temperatures between 10° and 40° and under all ordinary conditions of humidity and pressure.

TABLE III

Volumes (in Gallons) of Various Weights (in Pounds) of Linseed Oil

	Density of Oil (in grams per milliliter)															
	0.9190	0.9200	0.9210	0.9220	0.9230	0.9240	0.9250	0.9260	0.9270	0.9280	0.9290	0.9300	0.9310	0.9320	0.9330	0.9340	0.9350
Pounds	Gallons of Oil																
1	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
2	.26	.26	.26	.26	.26	.26	.26	.26	.26	.26	.26	.25	.25	.25	.25	.25	.25
3	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.39	.38
4	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.52	.51	.51	.51	.51
5	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.65	.64	.64	.64	.64	.64	.64
6	.78	.78	.78	.78	.78	.78	.78	.78	.78	.78	.77	.77	.77	.77	.77	.77	.77
7	.91	.91	.91	.91	.91	.91	.91	.91	.91	.90	.90	.90	.90	.90	.90	.90	.90
8	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.04	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
9	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.16	1.15
10	1.31	1.30	1.30	1.30	1.30	1.30	1.30	1.30	1.29	1.29	1.29	1.29	1.29	1.29	1.29	1.28	1.28
20	2.61	2.61	2.60	2.60	2.60	2.60	2.59	2.59	2.59	2.59	2.58	2.58	2.58	2.57	2.57	2.57	2.57
30	3.92	3.91	3.91	3.90	3.90	3.89	3.89	3.89	3.88	3.88	3.87	3.87	3.87	3.86	3.86	3.85	3.85
40	5.22	5.22	5.21	5.20	5.20	5 19	5.19	5.18	5.18	5.17	5.17	5.16	5.15	5.15	5.14	5.14	5.13
50	6.53	6.52	6.51	6.51	6.50	6.49	6.48	6.48	6.47	6.46	6.46	6.45	6.44	6.44	6.43	6.42	6.42
60	7.83	7.82	7.82	7.81	7.80	7.79	7.78	7.77	7.76	7.76	7 75	7 74	7.73	7.72	7.71	7.71	7.70
70	9.14	9.13	9.12	9.11	9.10	9.09	9.08	9.07	9.06	9.05	9.04	9.03	9.02	9.01	9.00	8.99	8.98
80	10.44	10.43	10.42	10.41	10.40	10.39	10.38	10.36	10.35	10.34	10.33	10.32	10.31	10.30	10.29	10.28	10.26
90	11.75	11.74	11.72	11.71	11.70	11.68	11.67	11.66	11.65	11.63	11.62	11.61	11.60	11.58	11.57	11.56	11.55
100	13.05	13.04	13.02	13.01	13.00	12.98	12.97	12.96	12.94	12.93	12.91	12.90	12.88	12.87	12.86	12.84	12.83
200	26.11	26.08	26.05	26.02	25.99	25.97	25.94	25.91	25.88	25.85	25.83	25.80	25.77	25.74	25.72	25.69	25.66
300	39.16	39.12	39.08	39.03	38.99	38.95	38.91	38.86	38.82	38.78	38.74	38.70	38.66	38.62	38.57	38.53	38.49
400	52.21	52.16	52.10	52.04	51.99	51.93	51.88	51.82	51.76	51.71	51.65	51.60	51.54	51.49	51.43	51.38	51.32
500	65.26	65.20	65.12	65.06	64.98	64.92	64.84	64.78	64.70	64.64	64.56	64.50	64.42	64.36	64.29	64.22	64.15
600	78.32	78.24	78.15	78.07	77.98	77.90	77.81	77.73	77.65	77.56	77.48	77.39	77.31	77.23	77.15	77.06	76.98
700	91.37	91.28	91.18	91.08	90.98	90.88	90.78	90.68	90.59	90.49	90.39	90.29	90.20	90.10	90.01	89.91	89.81
800	104.42	104.32	104.20	104.09	103.98	103.86	103.75	103.64	103.53	103.42	103.30	103.19	103.08	102.98	102.86	102.75	102.64
900	117.48	117.36	117.22	117.10	116.97	116.85	116.72	116.60	116.47	116.34	116.22	116.09	115.96	115.85	115.72	115.60	115.47
1000	130.53	130.40	130.25	130.11	129.97	129.83	129.69	129.55	129.41	129.27	129.13	128.99	128.85	128.72	128.58	128.44	128.30
2000	261.06	260.80	260.50	260.22	259.94	259.66	259.38	259.10	258.82	258.54	258.26	257.98	257.70	257.44	257.16	256.88	256.60
3000	391.59	391.20	390.75	390.33	389.91	389.49	389.07	388.65	388.23	387.81	387.39	386.97	386.55	386.16	385.74	385.32	384.90
4000	522.12	521.60	521.00	520.44	519.88	519.32	518.76	518.20	517.64	517.08	516.52	515.96	515.40	514.88	514.32	513.76	513.20
5000	652.65	652.00	651.25	650.55	649.85	649.15	648.45	647.75	647.05	646.35	645.65	644.95	644.25	643.60	642.90	642.20	641.50
6000	783.18	782.40	781.50	780.66	779.82	778.98	778.14	777.30	776.46	775.62	774.78	773.94	773.10	772.32	771.48	770.64	769.80
7000	913.71	912.80	911.75	910.77	909.79	908.81	907.83	906.85	905.87	904.89	903.91	902.93	901.95	901.04	900.06	899.08	898.10
8000	1044.24	1043.20	1042.00	1040.88	1039.76	1038.64	1037.52	1036.40	1035.28	1034.16	1033.04	1031.92	1030.80	1029.76	1028.64	1027.52	1026.40
9000	1174.77	1173.60	1172.25	1170.99	1169.73	1168.47	1167.21	1165.95	1164.69	1163.43	1162.17	1160.91	1159.65	1158.48	1157.22	1155.96	1154.70
10 000	1305.3	1304.0	1302.5	1301.1	1299.7	1298.3	1296.9	1295.5	1294.1	1292.7	1291.3	1289.9	1288.5	1287.2	1285.8	1284.4	1283.0

TABLE IV

Density of Turpentine at Temperatures from 10° to 40° C from its Density at 20° C

	Density at 20° C (in grams per milliliter)															
	0.8550	0.8560	0.8570	0.8580	0.8590	0.8600	0.8610	0.8620	0.8630	0.8640	0.8650	0.8660	0.8670	0.8680	0.8690	0.8700
Required temperature	Density at required temperature															
°C																
10	0.8631	0.8641	0.8651	0.8661	0.8671	0.8681	0.8691	0.8701	0.8711	0.8722	0.8732	0.8742	0.8752	0.8762	0.8772	0.8782
11	.8623	.8633	.8643	.8653	.8663	.8673	.8683	.8693	.8703	.8713	.8724	.8734	.8744	.8754	.8764	.8774
12	.8614	.8625	.8635	.8645	.8655	.8665	.8675	.8685	.8695	.8705	.8715	.8725	.8735	.8746	.8756	.8766
13	.8606	.8616	.8627	.8637	.8647	.8657	.8667	.8677	.8687	.8697	.8707	.8717	.8727	.8737	.8747	.8758
14	.8598	.8608	.8618	.8629	.8639	.8649	.8659	.8669	.8679	.8689	.8699	.8709	.8719	.8729	.8739	.8749
15	.8590	.8600	.8610	.8620	.8630	.8641	.8651	.8661	.8671	.8681	.8691	.8701	.8711	.8721	.8731	.8741
16	.8582	.8592	.8602	.8612	.8622	.8633	.8642	.8652	.8663	.8673	.8683	.8693	.8703	.8713	.8723	.8733
17	.8574	.8584	.8594	.8604	.8614	.8624	.8634	.8644	.8654	.8664	.8674	.8684	.8695	.8705	.8715	.8725
18	.8566	.8576	.8586	.8596	.8606	.8616	.8626	.8636	.8646	.8656	.8666	.8676	.8686	.8696	.8706	.8716
19	.8558	.8568	.8578	.8588	.8598	.8608	.8618	.8628	.8638	.8648	.8658	.8668	.8678	.8688	.8698	.8708
20	.8550	.8560	.8570	.8580	.8590	.8600	.8610	.8620	.8630	.8640	.8650	.8660	.8670	.8680	.8690	.8700
21	.8542	.8552	.8562	.8572	.8582	.8592	.8602	.8612	.8622	.8632	.8642	.8652	.8662	.8672	.8682	.8692
22	.8534	.8544	.8554	.8564	.8574	.8584	.8594	.8604	.8614	.8624	.8634	.8644	.8654	.8664	.8674	.8684
23	.8526	.8536	.8546	.8556	.8566	.8576	.8586	.8596	.8606	.8616	.8626	.8636	.8645	.8655	.8665	.8675
24	.8518	.8528	.8538	.8548	.8558	.8568	.8578	.8587	.8597	.8607	.8617	.8627	.8637	.8647	.8657	.8667
25	.8510	.8520	.8530	.8540	.8549	.8559	.8569	.8579	.8589	.8599	.8609	.8619	.8629	.8639	.8649	.8659
26	.8502	.8512	.8521	.8531	.8541	.8551	.8561	.8571	.8581	.8591	.8601	.8611	.8621	.8631	.8641	.8651
27	.8493	.8503	.8513	.8523	.8533	.8543	.8553	.8563	.8573	.8583	.8593	.8603	.8613	.8623	.8632	.8642
28	.8485	.8495	.8505	.8515	.8525	.8535	.8545	.8555	.8565	.8575	.8585	.8594	.8604	.8614	.8624	.8634
29	.8477	.8487	.8497	.8507	.8517	.8527	.8537	.8547	.8557	.8566	.8576	.8586	.8596	.8606	.8616	.8626
30	.8469	.8479	.8489	.8499	.8509	.8519	.8529	.8538	.8548	.8558	.8568	.8578	.8588	.8598	.8608	.8618
31	.8461	.8471	.8481	.8491	.8501	.8510	.8520	.8530	.8540	.8550	.8560	.8570	.8580	.8590	.8600	.8610
32	.8453	.8463	.8473	.8483	.8493	.8502	.8512	.8522	.8532	.8542	.8552	.8562	.8572	.8582	.8591	.8601
33	.8445	.8455	.8465	.8474	.8484	.8494	.8504	.8514	.8524	.8534	.8544	.8554	.8563	.8573	.8583	.8593
34	.8437	.8447	.8456	.8466	.8476	.8486	.8496	.8506	.8516	.8526	.8535	.8545	.8555	.8565	.8575	.8585
35	.8429	.8438	.8448	.8458	.8468	.8478	.8488	.8498	.8508	.8517	.8527	.8537	.8547	.8557	.8567	.8576
36	.8421	.8430	.8440	.8450	.8460	.8470	.8480	.8490	.8499	.8509	.8519	.8529	.8539	.8549	.8558	.8568
37	.8412	.8422	.8432	.8442	.8452	.8462	.8472	.8481	.8491	.8501	.8511	.8521	.8530	.8540	.8550	.8560
38	.8404	.8414	.8424	.8434	.8444	.8454	.8463	.8473	.8483	.8493	.8503	.8512	.8522	.8532	.8542	.8552
39	.8396	.8406	.8416	.8426	.8435	.8445	.8455	.8465	.8475	.8485	.8494	.8504	.8514	.8524	.8534	.8544
40	.8388	.8398	.8409	.8418	.8427	.8437	.8447	.8457	.8467	.8476	.8486	.8496	.8506	8516	.8526	.8535

TABLE V

Weights (in Pounds) of Various Volumes (in Gallons) of Turpentine

	Density of Turpentine (in grams per milliliter)													
	0.8470	0.8480	0.8490	0.8500	0.8510	0.8520	0.8530	0.8540	0.8550	0.8560	0.8570	0.8580	0.8590	0.8600
Gallons	**Weight of Turpentine (in pounds)**													
1	7.06	7.07	7.08	7.08	7.09	7.10	7.11	7.12	7.13	7.13	7.14	7.15	7.16	7.17
2	14.12	14.14	14.15	14 17	14.19	14.20	14.22	14.24	14.25	14.27	14.29	14.30	14.32	14.34
3	21.18	21.20	21.23	21.25	21.28	21.30	21.33	21.35	21.38	21.40	21.43	21.45	21.48	21.50
4	28.24	28.27	28.31	28.34	28.37	28.41	28.44	28.47	28.51	28.54	28.57	28.61	28.64	28.67
5	35.30	35.34	35.38	35.42	35.47	35.51	35.55	35.59	35.63	35.67	35.72	35.76	35.80	35.84
6	42.36	42.41	42.46	42.51	42.56	42.61	42.66	42.71	42.76	42.81	42.86	42.91	42.96	43.01
7	49.42	49.48	49.53	49.59	49.65	49.71	49.77	49.83	49.89	49.94	50.00	50.06	50.12	50.18
8	56.48	56.54	56.61	56.68	56.74	56.81	56.88	56.94	57.01	57.08	57.14	57.21	57.28	57.35
9	63.54	63.61	63.69	63.76	63.84	63.91	63.99	64.06	64.14	64.21	64.29	64.36	64.44	64.51
10	70.60	70.68	70.76	70.85	70.93	71.01	71.10	71.18	71.26	71.35	71.43	71.52	71.60	71.68
20	141.19	141.36	141.53	141.69	141.86	142.03	142.20	142.36	142.53	142.70	142.86	143.03	143.20	143.36
30	211.79	212.04	212.29	212.54	212.79	213.04	213.29	213.54	213.80	214.04	214.29	214.54	214.79	215.05
40	282.39	282.72	283.06	283.39	283.72	284.06	284.39	284.72	285.06	285.39	285.72	286.06	286.39	286.73
50	352.98	353.40	353.82	354.24	354.66	355.07	355.49	355.90	356.32	356.74	357.16	357.58	357.99	358.41
60	423.58	424.08	424.58	425.08	425.59	426.08	426.59	427.09	427.59	428.09	428.59	429.09	429.59	430.09
70	494.18	494.76	495.35	495.93	496.52	497.10	497.69	498.27	498.86	499.44	500.02	500.60	501.19	501.77
80	564.78	565.44	566.11	566.78	567.45	568.11	568.78	569.45	570.12	570.78	571.45	572.12	572.78	573.46
90	635.37	636.12	636.88	637.63	638.38	639.13	639.88	640.63	641.38	642.13	642.88	643.64	644.38	645.14
100	706.0	706.8	707.6	708.5	709.3	710.1	711.0	711.8	712.6	713.5	714.3	715.2	716.0	716.8
200	1411.9	1413.6	1415.3	1416.9	1418.6	1420.3	1422.0	1423.6	1425.3	1427.0	1428.6	1430.3	1432.0	1433.6
300	2117.9	2120.4	2122.9	2125.4	2127.9	2130.4	2132.9	2135.4	2138.0	2140.4	2142.9	2145.4	2147.9	2150.5
400	2823.9	2827.2	2830.6	2833.9	2837.2	2840.6	2843.9	2847.2	2850.6	2853.9	2857.2	2860.6	2863.9	2867.3
500	3529.8	3534.0	3538.2	3542.4	3546.6	3550.7	3554.9	3559.0	3563.2	3567.4	3571.6	3575.8	3579.9	3584.1
600	4235.8	4240.8	4245.8	4250.8	4255.9	4260.8	4265.9	4270.9	4275.9	4280.9	4285.9	4290.9	4295.9	4300.9
700	4941.8	4947.6	4953.5	4959.3	4965.2	4971.0	4976.9	4982.7	4988.6	4994.4	5000.2	5006.0	5011.9	5017.7
800	5647.8	5654.4	5661.1	5667.8	5674.5	5681.1	5687.8	5694.5	5701.2	5707.8	5714.5	5721.2	5727.8	5734.6
900	6353.7	6361.2	6368.8	6376.3	6383.8	6391.3	6398.8	6406.3	6413.8	6421.3	6428.8	6436.4	6443.8	6451.4
1000	7060	7068	7076	7085	7093	7101	7110	7118	7126	7135	7143	7152	7160	7168
2000	14119	14136	14153	14169	14186	14203	14220	14236	14253	14270	14286	14303	14320	14336
3000	21179	21204	21229	21254	21279	21304	21329	21354	21380	21404	21429	21454	21479	21505
4000	28239	28272	28306	28339	28372	28406	28439	28472	28506	28539	28572	28606	28639	28673
5000	35298	35340	35382	35424	35466	35507	35549	35590	35632	35674	35716	35758	35799	35841
6000	42358	42408	42458	42508	42559	42608	42659	42709	42759	42809	42859	42909	42959	43009
7000	49418	49476	49535	49593	49652	49710	49769	49827	49886	49944	50002	50060	50119	50177
8000	56478	56544	56611	56678	56745	56811	56878	56945	57012	57078	57145	57212	57278	57346
9000	63537	63612	63688	63763	63838	63913	63988	64063	64138	64213	64288	64364	64438	64514
10000	70597	70680	70764	70847	70931	71014	71098	71181	71265	71348	71431	71515	71598	71682

Gallons	Density of Turpentine (in grams per milliliter)												
	0.8610	0.8620	0.8630	0.8640	0.8650	0.8660	0.8670	0.8680	0.8690	0.8700	0.8710	0.8720	0.8730	0.8740
	Weight of Turpentine (in pounds)													
1	7.18	7.18	7.19	7.20	7.21	7.22	7.23	7.24	7.24	7.25	7.26	7.27	7.28	7.28
2	14.35	14.37	14.39	14.40	14.42	14.44	14.45	14.47	14.49	14.50	14.52	14.54	14.55	14.57
3	21.53	21.56	21.58	21.60	21.63	21.66	21.68	21.70	21.73	21.76	21.78	21.80	21.83	21.86
4	28.71	28.74	28.77	28.81	28.84	28.87	28.91	28.94	28.97	29.01	29.04	29.07	29.11	29.14
5	35.88	35.92	35.97	36.01	36.05	36.09	36.13	36.17	36.22	36.26	36.30	36.34	36.38	36.42
6	43.06	43.11	43.16	43.21	43.26	43.31	43.36	43.41	43.46	43.51	43.56	43.61	43.66	43.71
7	50.24	50.29	50.35	50.41	50.47	50.53	50.59	50.64	50.70	50.76	50.82	50.87	50.94	51.00
8	57.41	57.48	57.55	57.61	57.68	57.75	57.81	57.88	57.95	58.01	58.08	58.15	58.21	58.28
9	64.59	64.66	64.74	64.81	64.89	64.97	65.04	65.11	65.19	65.26	65.34	65.41	65.49	65.56
10	71.76	71.85	71.93	72.02	72.10	72.18	72.27	72.35	72.43	72.52	72.60	72.68	72.77	72.85
20	143.53	143.70	143.86	144.03	144.20	144.37	144.53	144.70	144.87	145.03	145.20	145.37	145.53	145.70
30	215.30	215.55	215.80	216.05	216.30	216.55	216.80	217.05	217.30	217.55	217.80	218.05	218.30	218.55
40	287.06	287.40	287.73	288.06	288.40	288.73	289.06	289.40	289.73	290.06	290.40	290.73	291.07	291.40
50	358.82	359.24	359.66	360.08	360.50	360.92	361.33	361.74	362.16	362.58	363.00	363.42	363.84	364.25
60	430.59	431.09	431.59	432.10	432.59	433.10	433.60	434.09	434.60	435.10	435.60	436.10	436.60	437.10
70	502.36	502.94	503.52	504.11	504.69	505.28	505.86	506.44	507.03	507.61	508.20	508.78	509.37	509.95
80	574.12	574.79	575.46	576.13	576.79	577.46	578.13	578.79	579.46	580.13	580.80	581.46	582.14	582.80
90	645.88	646.64	647.39	648.14	648.89	649.65	650.39	651.14	651.90	652.64	653.40	654.15	654.90	655.65
100	717.6	718.5	719.3	720.2	721.0	721.8	722.7	723.5	724.3	725.2	726.0	726.8	727.7	728.5
200	1435.3	1437.0	1438.6	1440.3	1442.0	1443.7	1445.3	1447.0	1448.7	1450.3	1452.0	1453.7	1455.3	1457.0
300	2153.0	2155.5	2158.0	2160.5	2163.0	2165.5	2168.0	2170.5	2173.0	2175.5	2178.0	2180.5	2183.0	2185.5
400	2870.6	2874.0	2877.3	2880.6	2884.0	2887.3	2890.6	2894.0	2897.3	2900.6	2904.0	2907.3	2910.7	2914.0
500	3588.2	3592.4	3596.6	3600.8	3605.0	3609.2	3613.3	3617.4	3621.6	3625.8	3630.0	3634.2	3638.4	3642.5
600	4305.9	4310.4	4315.9	4321.0	4325.9	4331.0	4336.0	4340.9	4346.0	4351.0	4356.0	3361.0	4366.0	4371.0
700	5023.6	5029.4	5035.2	5041.1	5046.9	5052.8	5058.6	5064.4	5070.3	5076.1	5082.0	5087.8	5093.7	5099.5
800	5741.2	5747.9	5754.6	5761.3	5767.9	5774.6	5781.3	5787.9	5794.6	5801.3	5808.0	5814.6	5821.4	5828.0
900	6458.8	6466.4	6473.9	6481.4	6488.9	6496.5	6503.9	6511.4	6519.0	6526.4	6534.0	6541.5	6549.0	6556.5
1000	7176	7185	7193	7202	7210	7218	7227	7235	7243	7252	7260	7268	7277	7285
2000	14353	14370	14386	14403	14420	14437	14453	14470	14487	14503	14520	14537	14553	14570
3000	21530	21555	21580	21605	21630	21655	21680	21705	21730	21755	21780	21805	21830	21855
4000	28706	28740	28773	28806	28840	28873	28906	28940	28973	29006	29040	29073	29107	29140
5000	35882	35924	35966	36008	36050	36092	36133	36174	36216	36258	36300	36342	36384	36425
6000	43059	43109	43159	43210	43259	43310	43360	43409	43460	43510	43560	43610	43660	43710
7000	50236	50294	50352	50411	50469	50528	50586	50644	50703	50761	50820	50878	50937	50995
8000	57412	57479	57546	57613	57679	57746	57813	57879	57946	58013	58080	58146	58214	58280
9000	64588	64664	64739	64814	64889	64965	65039	65114	65190	65264	65340	65415	65490	65565
10000	71765	71849	71932	72016	72099	72183	72266	72349	72433	72516	72600	72683	72767	72850

TABLE VI

Volumes (in Gallons) of Various Weights (in Pounds) of Turpentine

	Density of Turpentine (in grams per milliliter)													
	0.8470	0.8480	0.8490	0.8500	0.8510	0.8520	0.8530	0.8540	0.8550	0.8560	0.8570	0.8580	0.8590	0.8600
Pounds	**Gallons of Turpentine**													
1	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
2	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28
3	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42	.42
4	.57	.57	.57	.56	.56	.56	.56	.56	.56	.56	.56	.56	.56	.56
5	.71	.71	.71	.71	.70	.70	.70	.70	.70	.70	.70	.70	.70	.70
6	.85	.85	.85	.85	.85	.84	.84	.84	.84	.84	.84	.84	.84	.84
7	.99	.99	.99	.99	.99	.99	.98	.98	.98	.98	.98	.98	.98	.98
8	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.12	1.12	1.12	1.12	1.12	1.12	1.12
9	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.26	1.26	1.26	1.26	1.26	1.26	1.26
10	1.42	1.41	1.41	1.41	1.41	1.41	1.41	1.40	1.40	1.40	1.40	1.40	1.40	1.40
20	2.83	2.83	2.83	2.82	2.82	2.82	2.81	2.81	2.81	2.80	2.80	2.80	2.79	2.79
30	4.25	4.24	4.24	4.23	4.23	4.22	4.22	4.21	4.21	4.20	4.20	4.19	4.19	4.19
40	5.67	5.66	5.65	5.65	5.64	5.63	5.63	5.62	5.61	5.61	5.60	5.59	5.59	5.58
50	7.08	7.07	7.07	7.06	7.05	7.04	7.03	7.02	7.02	7.01	7.00	6.99	6.98	6.98
60	8.50	8.49	8.48	8.47	8.46	8.45	8.44	8.43	8.42	8.41	8.40	8.39	8.38	8.37
70	9.92	9.90	9.89	9.88	9.87	9.86	9.85	9.83	9.82	9.81	9.80	9.79	9.78	9.77
80	11.33	11.32	11.31	11.29	11.28	11.27	11.25	11.24	11.23	11.21	11.20	11.19	11.17	11.16
90	12.75	12.73	12.72	12.70	12.69	12.67	12.66	12.64	12.63	12.61	12.60	12.58	12.57	12.56
100	14.16	14.15	14.13	14.12	14.10	14.08	14.07	14.05	14.03	14.02	14.00	13.98	13.97	13.95
200	28.33	28.30	28.26	28.23	28.20	28.16	28.13	28.10	28.06	28.03	28.00	27.97	27.93	27.90
300	42.49	42.44	42.39	42.34	42.29	42.25	42.20	42.15	42.10	42.05	42.00	41.95	41.90	41.85
400	56.66	56.59	56.53	56.46	56.39	56.33	56.26	56.20	56.13	56.06	56.00	55.93	55.87	55.80
500	70.82	70.74	70.66	70.58	70.49	70.41	70.33	70.24	70.16	70.08	70.00	69.92	69.84	69.76
600	84.99	84.89	84.79	84.69	84.59	84.49	84.40	84.29	84.19	84.10	84.00	83.90	83.80	83.71
700	99.15	99.04	98.92	98.80	98.69	98.57	98.46	98.34	98.22	98.11	98.00	97.88	97.77	97.66
800	113.32	113.19	113.05	112.92	112.78	112.66	112.53	112.39	112.26	112.13	112.00	111.86	111.74	111.61
900	127.48	127.33	127.18	127.04	126.88	126.74	126.59	126.44	126.29	126.14	126.00	125.85	125.70	125.56
1000	141.65	141.48	141.32	141.15	140.98	140.82	140.66	140.49	140.32	140.16	140.00	139.83	139.67	139.51
2000	283.30	282.97	282.63	282.30	281.96	281.64	281.32	280.98	280.64	280.32	280.00	279.66	279.34	279.02
3000	424.95	424.45	423.94	423.45	422.94	422.46	421.98	421.47	420.96	420.48	420.00	419.49	419.01	418.53
4000	566.60	565.93	565.26	564.60	563.92	563.28	562.64	561.96	561.28	560.64	560.00	559.32	558.68	558.04
5000	708.24	707.42	706.58	705.75	704.90	704.10	703.30	702.45	701.60	700.80	700.00	699.15	698.35	697.55
6000	849.89	848.90	847.89	846.90	845.88	844.92	843.96	842.94	841.92	840.96	840.00	838.98	838.02	837.06
7000	991.54	990.38	989.20	988.05	986.86	985.74	984.62	983.43	982.24	981.12	980.00	978.81	977.69	976.57
8000	1133.19	1131.86	1130.52	1129.20	1127.84	1126.56	1125.28	1123.92	1122.56	1121.28	1120.00	1118.64	1117.36	1116.08
9000	1274.84	1273.35	1271.84	1270.35	1268.82	1267.38	1265.94	1264.41	1262.88	1261.44	1260.00	1258.47	1257.03	1255.59
10000	1416.5	1414.8	1413.2	1411.5	1409.8	1408.2	1406.6	1404.9	1403.2	1401.6	1400.0	1398.3	1396.7	1395.1

	Density of Turpentine (in grams per milliliter)												
	0.8610	0.8620	0.8630	0.8640	0.8650	0.8660	0.8670	0.8680	0.8690	0.8700	0.8710	0.8720	0.8730	0.8740
Pounds	**Gallons of Turpentine**													
1	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
2	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.28	.27	.27
3	.42	.42	.42	.42	.42	.42	.42	.41	.41	.41	.41	.41	.41	.41
4	.56	.56	.56	.56	.55	.55	.55	.55	.55	.55	.55	.55	.55	.55
5	.70	.70	.70	.69	.69	.69	.69	.69	.69	.69	.69	.69	.69	.69
6	.84	.84	.83	.83	.83	.83	.83	.83	.83	.83	.83	.83	.82	.82
7	.98	.97	.97	.97	.97	.97	.97	.97	.97	.97	.96	.96	.96	.96
8	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.11	1.10	1.10	1.10	1.10	1.10	1.10
9	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.24	1.24	1.24	1.24	1.24	1.24	1.24
10	1.39	1.39	1.39	1.39	1.39	1.39	1.38	1.38	1.38	1.38	1.38	1.38	1.37	1.37
20	2.79	2.78	2.78	2.78	2.77	2.77	2.77	2.76	2.76	2.76	2.76	2.75	2.75	2.75
30	4.18	4.18	4.17	4.17	4.16	4.16	4.15	4.15	4.14	4.14	4.13	4.13	4.12	4.12
40	5.57	5.57	5.56	5.55	5.55	5.54	5.54	5.53	5.52	5.52	5.51	5.50	5.50	5.49
50	6.97	6.96	6.95	6.94	6.94	6.93	6.92	6.91	6.90	6.90	6.89	6.88	6.87	6.86
60	8.36	8.35	8.34	8.33	8.32	8.31	8.30	8.29	8.28	8.27	8.26	8.25	8.24	8.24
70	9.75	9.74	9.73	9.72	9.71	9.70	9.69	9.67	9.66	9.65	9.64	9.63	9.62	9.61
80	11.15	11.13	11.12	11.11	11.10	11.08	11.07	11.06	11.04	11.03	11.02	11.01	10.99	10.98
90	12.54	12.53	12.51	12.50	12.48	12.47	12.45	12.44	12.42	12.41	12.40	12.38	12.37	12.35
100	13.93	13.92	13.90	13.89	13.87	13.85	13.84	13.82	13.81	13.79	13.77	13.76	13.74	13.73
200	27.87	27.84	27.80	27.77	27.74	27.71	27.68	27.64	27.61	27.58	27.55	27.52	27.48	27.45
300	41.80	41.75	41.71	41.66	41.61	41.56	41.51	41.47	41.42	41.37	41.32	41.27	41.23	41.18
400	55.74	55.67	55.61	55.54	55.48	55.42	55.35	55.29	55.22	55.16	55.10	55.03	54.97	54.91
500	69.67	69.59	69.51	69.43	69.35	69.27	69.19	69.11	69.03	68.95	68.87	68.79	68.71	68.63
600	83.60	83.51	83.41	83.32	83.22	83.12	83.03	82.93	82.84	82.74	82.64	82.55	82.45	82.36
700	97.54	97.43	97.31	97.20	97.09	96.98	96.87	96.75	96.64	96.53	96.42	96.31	96.19	96.09
800	111.47	111.34	111.22	111.09	110.96	110.83	110.70	110.58	110.45	110.32	110.19	110.06	109.94	109.81
900	125.41	125.26	125.12	124.97	124.83	124.69	124.54	124.40	124.25	124.11	123.97	123.82	123.68	123.54
1000	139.34	139.18	139.02	138.86	138.70	138.54	138.38	138.22	138.06	137.90	137.74	137.58	137.42	137.27
2000	278.68	278.36	278.04	277.72	277.40	277.08	276.76	276.44	276.12	275.80	275.48	275.16	274.84	274.54
3000	418.02	417.54	417.06	416.58	416.10	415.62	415.14	414.66	414.18	413.70	413.22	412.74	412.26	411.80
4000	557.36	556.72	556.08	555.44	554.80	554.16	553.52	552.88	552.24	551.60	550.96	550.32	549.68	549.07
5000	696.70	695.90	695.10	694.30	693.50	692.70	691.90	691.10	690.30	689.50	688.70	687.90	687.10	686.34
6000	836.04	835.08	834.12	833.16	832.20	831.24	830.28	829.32	828.36	827.40	826.44	825.48	824.52	823.61
7000	975.38	974.26	973.14	972.02	970.90	969.78	968.66	967.54	966.42	965.30	964.18	963.06	961.94	960.88
8000	1114.72	1113.44	1112.16	1110.88	1109.60	1108.32	1107.04	1105.76	1104.48	1103.20	1101.92	1100.64	1099.36	1098.14
9000	1254.06	1252.62	1251.18	1249.74	1248.30	1246.86	1245.42	1243.98	1242.54	1241.10	1239.66	1238.22	1236.78	1235.41
10000	1393.4	1391.8	1390.2	1388.6	1387.0	1385.4	1383.8	1382.2	1380.6	1379.0	1377.4	1375.8	1374.2	1372.7

SUPPLEMENT TO TECHNOLOGIC PAPER No. 9

TABLE 1

For reducing observed specific gravities of turpentine at various temperatures to true specific gravity at 60°/60° F

[NOTE.—Tables 1 and 2 were calculated, using the expansion data for turpentine shown in Tech. Paper No. 9, Bureau of Standards, and Proc. Am. Soc. for Testing Materials, Vol. XIV, 1914, p. 115. It is assumed that the instrument used for determining the specific gravity and degrees Baumé is of glass, having a coefficient of cubical expansion of 0.000023 per degree C. In Tables 2, 3, and 4 the American Standard Baumé scale, modulus 140, is used. In the use of the tables observed values should be corrected for instrumental errors.]

Observed temperature in degrees Fahrenheit	Observed specific gravity				
	0.8400	0.8500	0.8600	0.8700	0.8800
	Specific gravity at 60°/60° F.				
30	.....	.....	0.8467	0.8567	0.8667
35	.....	.....	.8490	.8590	.8690
40	.....	0.8412	.8512	.8612	.8712
45	.....	.8434	.8534	.8634	.8734
50	.....	.8456	.8556	.8656	.8756
51	.....	.8460	.8560	.8660	.8760
52	.....	.8465	.8565	.8665	.8765
53	.....	.8469	.8569	.8669	.8769
54	.....	.8474	.8574	.8674	.8774
55	.....	.8478	.8578	.8678	.8778
56	.....	.8482	.8582	.8682	.8782
57	.....	.8487	.8587	.8887	.8787
58	.....	.8491	.8591	.6691	.8791
59	.....	.8496	.8596	.8696	.8796
60	0.8400	.8500	.8600	.8700	.8800
61	.8405	.8505	.8605	.8705	.....
62	.8409	.8509	.8609	.8709	.....
63	.8413	.8513	.8613	.8713	.....
64	.8417	.8517	.8617	.8717	.....
65	.8422	.8522	.8622	.8722	.....
66	.8426	.8526	.8626	.8726	.....
67	.8430	.8530	.8630	.8730	.....
68	.8435	.8535	.8635	.8735	.....
69	.8439	.8539	.8639	.8739	.....
70	.8444	.8544	.8644	.8744	.....
75	.8466	.8566	.8666	.8766	.....
80	.8488	.8588	.8688	.8788	.....
85	.8511	.8611	.8711	.....	.....
90	.8533	.8633	.8733	.....	.....
95	.8555	.8655	.8755	.....	.....
100	.8577	.8677	.8777	.....	.....
105	.8599	.8699	.8799	.....	.....
110	.8622	.8722	.....	.....	.....
115	.8644	.8744	.....	.....	.....
120	.8666	.8766	.....	.....	.....

TABLE 2

For reducing observed degrees Baumé of turpentine at various temperatures to true degrees Baumé at 60° F

Observed temperature in degrees Fahrenheit	Observed degrees Baumé							
	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0
	Degrees Baumé at 60° F							
30	31.4	32.5	33.5	34.5	35.6	....	....	....
35	31.0	32.0	33.1	34.1	35.1	....	....	....
40	30.6	31.6	32.6	33.7	34.7	35.7	....	....
45	30.2	31.2	32.2	33.2	34.3	35.3	....	....
50	29.8	30.8	31.8	32.8	33.8	34.8	35.8	....
51	29.7	30.7	31.7	32.8	33.8	34.8	35.8	....
52	29.6	30.6	31.6	32.7	33.7	34.7	35.7	....
53	29.6	30.6	31.6	32.6	33.6	34.6	35.6	....
54	29.5	30.5	31.5	32.5	33.5	34.5	35.5	....
55	29.4	30.4	31.4	32.4	33.4	34.4	35.4	....
56	29.3	30.3	31.3	32.3	33.3	34.3	35.3	....
57	29.2	30.2	31.2	32.2	33.2	34.2	35.2	....
58	29.2	30.2	31.2	32.2	33.2	34.2	35.2	....
59	29.1	30.1	31.1	32.1	33.1	34.1	35.1	....
60	29.0	30.0	31.0	32.0	33.0	34.0	35.0	36.0
61	....	29.9	30.9	31.9	32.9	33.9	34.9	35.9
62	....	29.8	30.8	31.8	32.8	33.8	34.8	35.8
63	....	29.8	30.8	31.8	32.8	33.8	34.8	35.7
64	....	29.7	30.7	31.7	32.7	33.7	34.7	35.7
65	....	29.6	30.6	31.6	32.6	33.6	34.6	35.6
66	....	29.5	30.5	31.5	32.5	33.5	34.5	35.5
67	....	29.4	30.4	31.4	32.4	33.4	34.4	35.4
68	....	29.4	30.4	31.4	32.3	33.3	34.3	35.3
69	....	29.3	30.3	31.3	32.2	33.2	34.2	35.2
70	....	29.2	30.2	31.2	32.2	33.2	34.2	35.1
75	....	....	29.8	30.8	31.8	32.7	33.7	34.7
80	....	....	29.4	30.4	31.4	32.3	33.3	34.3
85	....	....	29.0	30.0	30.9	31.9	32.9	33.8
90	....	....	....	29.6	30.5	31.5	32.4	33.4
95	....	....	....	29.2	30.1	31.1	32.0	33.0
100	....	....	....	....	29.7	30.7	31.6	32.6
105	....	....	....	....	29.3	30.3	31.2	32.2
110	....	....	....	....	28.9	29.8	30.8	31.7
115	....	....	....	....	....	29.4	30.4	31.3
120	....	....	....	....	....	29.0	30.0	30.9

BUREAU OF STANDARDS, *October 25, 1915.*

(OVER)

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SUPPLEMENT TO TECHNICAL PAPER No. 9

TABLE 3

Showing the Degrees Baumé, Pounds Per Gallon, and Gallons Per Pound Corresponding to Various Specific Gravities of Turpentine

Specific gravity 60°/60° Fahrenheit	Degrees Baumé (modulus 140)	Pounds per gallon	Gallons per pound
0.860	32.79	7.161	0.1396
.861	32.60	7.169	.1395
.862	32.41	7.178	.1393
.863	32.22	7.186	.1392
.864	32.04	7.194	.1390
.865	31.85	7.203	.1388
.866	31.66	7.211	.1387
.867	31.48	7.219	.1385
.868	31.29	7.228	.1384
.869	31.10	7.236	.1382
.870	30.92	7.244	.1380
.871	30.74	7.253	.1379
.872	30.55	7.261	.1377
.873	30.37	7.270	.1376
.874	30.18	7.278	.1374
.875	30.00	7.286	.1372

(OVER)

TABLE 4

Showing the Specific Gravity, Pounds Per Gallon, and Gallons Per Pound Corresponding to Various Degrees Baumé of Turpentine

Degrees Baumé (modulus 140)	Specific gravity 60°/60° Fahrenheit	Pounds per gallon	Gallons per pound
30. 0	0. 8750	7. 286	0. 1372
30. 1	. 8745	7. 282	. 1373
30. 2	. 8739	7. 277	. 1374
30. 3	. 8734	7. 273	. 1375
30. 4	. 8728	7. 268	. 1376
30. 5	. 8723	7. 264	. 1377
30. 6	. 8717	7. 259	. 1378
30. 7	. 8712	7. 254	. 1379
30. 8	. 8706	7. 249	. 1379
30. 9	. 8701	7. 245	. 1380
31. 0	. 8696	7. 241	. 1381
31. 1	. 8690	7. 236	. 1382
31. 2	. 8685	7. 232	. 1383
31. 3	. 8679	7. 227	. 1384
31. 4	. 8674	7. 223	. 1385
31. 5	. 8669	7. 218	. 1385
31. 6	. 8663	7. 214	. 1386
31. 7	. 8658	7. 210	. 1387
31. 8	. 8653	7. 205	. 1388
31. 9	. 8647	7. 201	. 1389
32. 0	. 8642	7. 196	. 1390
32. 1	. 8637	7. 192	. 1390
32. 2	. 8631	7. 187	. 1391
32. 3	. 8626	7. 183	. 1392
32. 4	. 8621	7. 178	. 1393
32. 5	. 8615	7. 173	. 1394
32. 6	. 8610	7. 169	. 1395
32. 7	. 8605	7. 165	. 1396
32. 8	. 8600	7. 161	. 1396
32. 9	. 8594	7. 156	. 1397
33. 0	. 8589	7. 152	. 1398

(OVER)

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DEPARTMENT OF COMMERCE AND LABOR

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 10

MELTING POINTS OF FIRE BRICKS

BY

C. W. KANOLT, Assistant Physicist

Bureau of Standards

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MELTING POINTS OF FIRE BRICKS

By C. W. Kanolt

We are accustomed to thinking of a melting point as a temperature at which a substance changes from a condition in which it does not flow perceptibly under its own weight to a condition in which it flows readily. However, no rational definition of the melting point can be based upon this conception. For example, when glass is heated, the transition from its ordinary condition to a distinctly fluid condition is a very gradual one and occupies a range of several hundred degrees. Some other substances which possess perfectly definite temperatures of transition to a fluid phase undergo changes resembling fusion at lower temperatures. Solids in general become softer when heated; they may become so soft as to yield to their own surface tension, with the result that sharp corners are rounded off. Rutile, in its natural, slightly impure condition, melts at about 1700° C. The melting point is very definite, there being a sharp transition from a rather soft solid to a liquid of low viscosity, with a considerable absorption of heat. Yet at temperatures 100° or more below the melting point, corners are rounded off and small particles become sintered together. The sintering of clay is probably a similar phenomenon of surface tension. Clay exists generally in the form of extremely fine particles, its unusually slight solubility in water accounting for this condition. Fine particles are more readily united by surface tension than large ones.

A melting point can be precisely and rationally defined only as the temperature at which a crystalline or anisotropic phase and an amorphous or isotropic phase of the same composition can

exist in contact in equilibrium. In harmony with this, one might define a solid as a crystalline substance, and a fluid as a substance not crystalline; however, these definitions of solid and fluid would lead to results quite different from our ordinary conceptions, as they would require us to consider glass, even silica glass, as a fluid, and certain "anisotropic liquids" whose viscosities are even less than that of water, as solids. Perhaps it is better to leave solid and liquid or fluid as general terms without precise definitions.

While the above definition of melting point is satisfactory for the case of a pure substance, so complex a mixture as an ordinary fire brick usually has no single definite melting point according to this definition, since several anisotropic phases may be present, all differing in composition from the isotropic phase produced by fusion. We can, then, only select the temperature at which the transition from a rigid to a fluid state seems most distinct, and can call this the melting point only by apology.

In the case of fire bricks the transition temperatures so found are fortunately sufficiently definite to make their determination of practical value. I have taken as the melting point the lowest temperature at which a small piece of the brick could be distinctly seen to flow. Experiments showing the degree of definiteness of this temperature will be described.

The melting point of a brick is, of course, not the only property to be considered in determining its fitness for a given purpose. Its crushing strength cold, its behavior under load conditions when heated, and its resistance to fluxes may all be important. The present paper deals only with melting points.

A large number of the brick samples tested were kindly furnished by Dr. A. V. Bleininger, being identical with samples tested by Bleininger and Brown [1] under load conditions at 1300° C, this work being carried out at the Pittsburgh testing station of this bureau, which station was at that time the technologic branch of the United States Geological Survey. The chemical composition, crushing strength cold, porosity and density of these samples are given by Bleininger and Brown. They also determined the Seger

[1] Bureau of Standards Technologic Papers, No. 7; 1912.

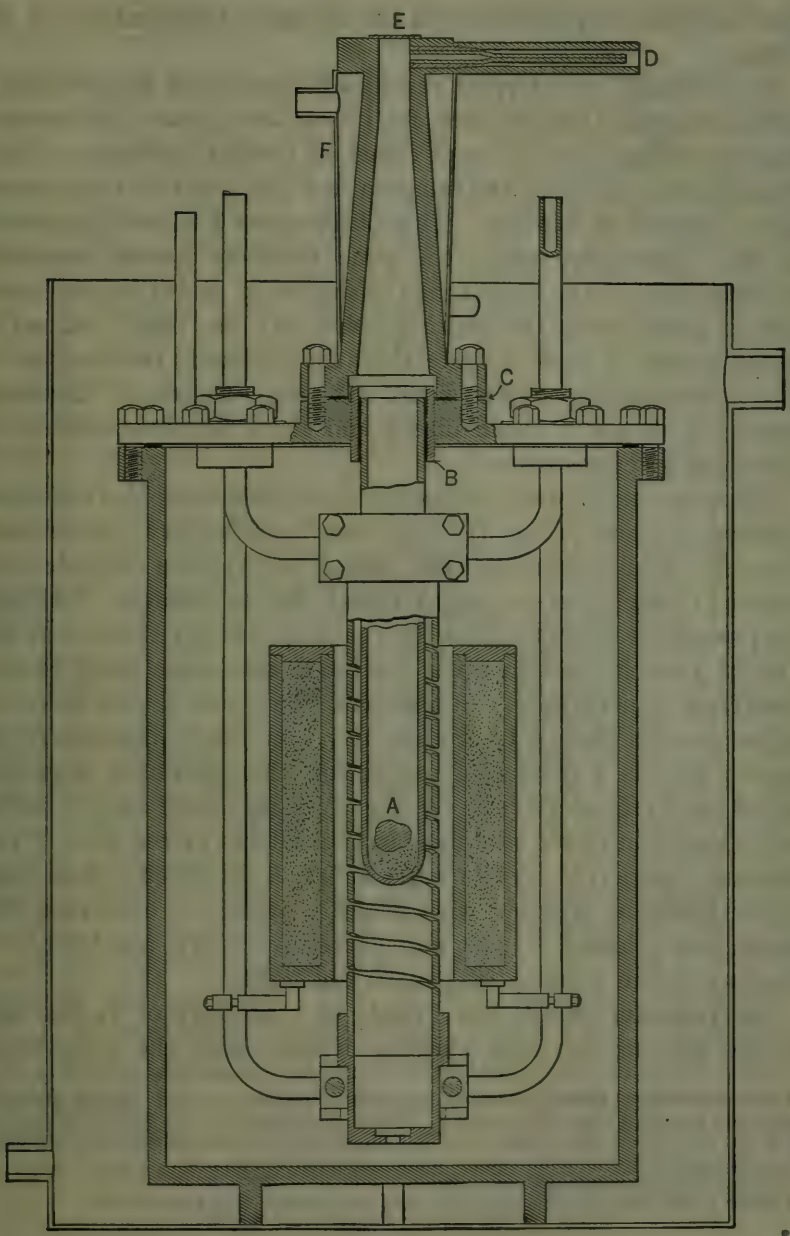


Fig. 1

cone numbers corresponding to the softening temperatures of the bricks.[2]

It is difficult to interpret results obtained with Seger cones in terms of actual temperatures, for it has been shown by Simonis [3] that the falling over of Seger cones, of certain numbers at least, depends not only upon the temperature, but also to a large extent upon the rate of heating. This observation has been confirmed in this laboratory, using the cone numbers having softening temperatures in the same range as fire brick, and it has appeared that in many cases the melting point of a fire brick, defined as stated above, is more definite than the softening temperature of the corresponding Seger cone. It has, therefore, appeared preferable to use a more direct and more accurate method of determining temperatures.

The experiments were conducted in an Arsem graphite resistance vacuum furnace [4] (Fig. 1). In some preliminary experiments upon fire bricks samples were heated in graphite crucibles and exposed to such gases as might remain in the furnace. Although the pressure was kept as low as 2 mm of mercury, there was still a slight reducing action upon the brick, and some samples were blackened superficially. Subsequent work has shown that the action was insufficient to produce any very great difference in the results, but, as a matter of precaution, the specimens were protected by a refractory tube (*A*, Fig. 1) being placed upon a bed of white alundum (fused alumina) in the bottom of the tube. This tube was supported by the brass collar, *B*, in which it was made to fit tightly by winding with asbestos string, or otherwise, and which was soldered to the lead gasket by which the joint *C* in the top of the furnace was made air tight.

The refractory tubes were made of a mixture of 72 per cent kaolin and 28 per cent alumina, these being the proportions

[2] See also Hofman and Demond: Trans. Am. Inst. Mining Eng., 24, p. 42; 1894. Hofman: Trans. Am. Inst. Mining Eng., 25, p. 3, 1895; 28, p. 435; 1898. Hofman and Stroughton: Trans. Am. Inst. Mining Eng., 28, p. 440; 1898. Gary: Mitt. k. tech. Versuchsanstalten, 14, p. 63; 1896. Jochum: Thonindustrie Zs., 27, p. 764; 1903. Weber: Trans. Am. Inst. Mining Eng., 35, p. 637; 1904.

[3] Simonis: Thonindustrie Zs., 32, p. 1764; 1908.

[4] Arsem: J. Am. Chem. Soc., 28, p. 921, 1906; Trans. Am. Electroch. Soc., 9, p. 153, 1906.

for the formation of sillimanite, Al_2O_3,SiO_2. According to Shepherd and Rankin [5] pure sillimanite melts at 1811°. The sillimanite tubes were found to melt at about this temperature. Kaolin tubes were used for some samples of relatively low melting points. Either sillimanite or kaolin tubes were used with all fire bricks melting below 1800°. The chromite and magnesia bricks were melted in graphite crucibles without protecting tubes. The experiments were made rapidly and the graphite had little action on the samples until after fusion had occurred and the melting point had been determined. Magnesia tubes may be used in place of sillimanite tubes, and they have the advantage of a higher melting point; but all magnesia tubes that have been tried have been found to be very easily cracked by changes of temperature, and to be so porous as to afford little protection from the gases of the furnace. When a sillimanite or kaolin tube was used, 20 to 30 minutes was consumed in heating the furnace to a little below the melting point of the sample. This initial heating could be performed much more quickly, so far as the furnace is concerned, but more rapid heating would be likely to crack the tube. When the temperature had nearly reached the melting point it was raised much more slowly. When these protecting tubes were used the samples showed only very slight signs of reduction. In certain experiments made with this apparatus—for example, the determination of the melting point of platinum as a check upon the work—it has been desirable to still further diminish the chances of the presence of reducing gases. This has been accomplished by the device shown at *D* in Fig. 1, which consists of a glass tube drawn out into a fine capillary and leading into the furnace. An outer brass tube protects the capillary. This capillary admits a slow current of air to the inside of the refractory tube, and the air passes out through the pores of the tube into the interior of the furnace. By working the vacuum pump continually the pressure in the furnace was kept down to a few millimeters of mercury, in spite of the influx of air. This process was, of course, injurious to

[5] Shepherd and Rankin: Am. Jour. Sci., 28, p. 301; 1909.

the graphite heater, but several such experiments could be made with one heater before it was burned out.

While the sample was being heated it was observed through the window *E* at the top of the furnace. A glass window was used here in place of the mica window provided by the makers of the furnace. The glass was attached by a mixture of rosin and beeswax. To keep this material cool an additional water jacket, *F*, was applied to the part of the furnace projecting above the water of the tank.

The temperatures were determined by means of a Morse optical pyrometer of the Holborn-Kurlbaum type,[6] which was sighted vertically downward through the furnace window. The current in the pyrometer lamp was measured with a Siemens and Halske milliammeter with a shunt. This instrument was calibrated several times, and its very small temperature coefficient was taken into account. Its readings are certainly reliable to 0.001 ampere and probably to 0.0005 ampere.

The carbon-filament pyrometer lamp was one of the standard lamps of the bureau, and had been thoroughly aged, and had been accurately calibrated by several observers before the beginning of the investigation, and again, by a different method, toward its close. In the first calibration it was sighted into a platinum-resistance furnace in which black-body conditions were obtained, and the temperature of which was measured by platinum, platinum-rhodium thermocouples. These thermocouples had been calibrated against the freezing points of pure metals. In the second calibration the lamp was calibrated against the freezing points of metals directly, without the intermediation of thermocouples. The metals used were copper, silver, and the copper-silver eutectic, which freeze at 1083°, 961°, and 779°, respectively. These were placed in Acheson graphite crucibles of the form shown in Fig. 2, about 100 grams of metal being used in each. The pyrometer was sighted downward into the central graphite tube, of which the inside diameter was 6 mm and the wall thickness 1

[6] Holborn and Kurlbaum: Sitzber. d. k. Akad. d. Wissensch. zu Berlin, June 13, p. 712, 1901; Ann. d. Phys., 10, p. 225; 1902. Waidner and Burgess: Bull. Bureau of Standards, 1, No. 2; 1904. Mendenhall: Phys. Rev., 33, p. 74; 1911. Henning: Zs. f. Instrumentenkunde, 30, p. 61; 1910.

mm. The crucibles were heated or cooled gradually, while observations were made every 10 to 20 seconds, and the resulting heating or cooling curves were plotted. A typical curve is shown in Fig. 3. In this diagram a change of temperature of 1° corresponds to a change of current of about 0.0005 ampere. By means of the three known temperatures, the relation between the current in the lamp and the temperature was expressed in the form, $C = a + bt + ct^2$.

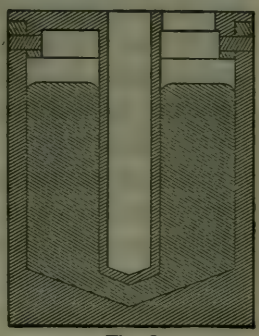


Fig. 2

This method presented two possible sources of error to be especially considered, namely, the conduction of heat along the inner graphite tube, and the departure of the interior of this tube from black-body conditions. If the conduction of heat along the tube introduced appreciable error, the observed temperatures

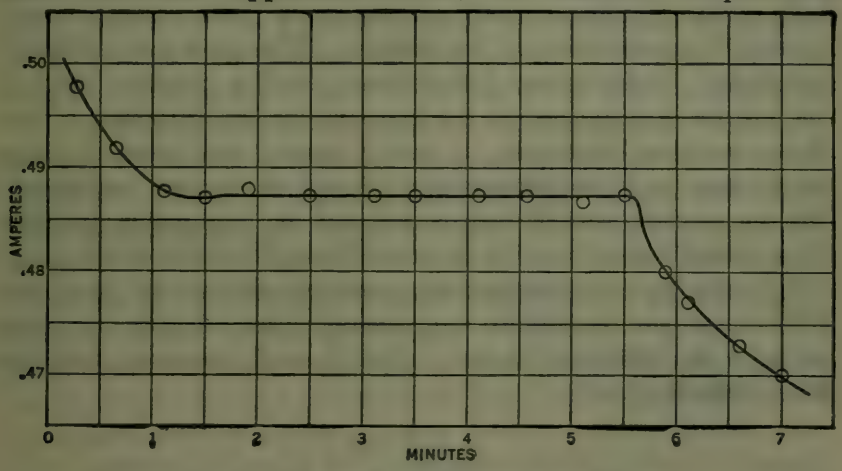


Fig 3.—*Calibration of lamp at freezing point of silver*

would be too high with rising temperature, when the furnace heater would be hotter than the metal, and too low with falling temperature, when the reverse would be true. The fact that the results from the heating curves obtained with copper and silver were in very close agreement with those from the cooling curves shows that the errors from conduction are negligible; and these and

numerous other observations have indicated that such a tube when made of graphite, which is itself nearly perfectly black, is a very good black body. Using the copper-silver eutectic somewhat unsatisfactory results were obtained with heating curves, the trouble appearing to be in the behavior of the alloy rather than in the temperature measurement. In this case only cooling curves were used for the calibration. The calibration of the lamp at this temperature is relatively unimportant, since none of the melting points here given correspond to a lamp temperature below the melting point of silver. The results of this calibration agreed with those obtained by the first method within 1°, from 700° to 1300°, which includes all lamp temperatures used in this work. Near the close of the investigation the pyrometer lamp was accidentally overheated, and it was necessary to recalibrate it. This time, only the cooling-curve method was used.

As the melting points to be measured were above the working limit of the pyrometer lamp, an absorption glass was interposed between the pyrometer and the furnace. This glass was calibrated as follows: In the Arsem furnace was placed a graphite crucible, the interior of which, when the furnace was hot, furnished a field of very uniform brightness. A steady current was passed through the furnace and the temperature allowed to become stationary. The temperature was then measured with the pyrometer, and also the apparent temperature as observed through the absorption glass. If T_1 is the absolute temperature, observed without the glass, and T_2 is the apparent absolute temperature observed with the glass, we have the following relation, which is easily deduced from the Wien radiation law:

$$\frac{1}{T_2} - \frac{1}{T_1} = A$$

The constant, A, was determined in this way with several different furnace temperatures, and the results were in close agreement. The mean value of A was 0.0002249. The values of the constants of Wien's law do not enter into the work.

The glass furnace window absorbed and reflected a small amount of light and it was necessary to apply a correction for this. The constant of this glass was determined in the same

way as that of the absorption glass, and was found to be 0.0000040. The correction in degrees depends, of course, upon the temperature; it is about 15° at the melting point of ordinary fire brick.

As a check upon the whole apparatus, a determination of the melting point of platinum was made. A piece of platinum foil was placed within two magnesia tubes, one within the other, in the place of the single tube shown at *A* (Fig. 1), and a slow current of air was admitted at *D*. Fairly good black-body conditions were obtained, but the platinum was faintly visible. The observed melting point was 1750°. The value accepted by the Bureau of Standards as the melting point of platinum is 1755°. After the pyrometer lamp had been overheated and recalibrated, this test was repeated. In place of magnesia tubes, tubes of a mixture of magnesia and alumina,[7] obtained from the Königliche Porzellan-Manufactur, Berlin, were used. These were found to be more satisfactory than magnesia tubes, being much less porous and less easily cracked. The material softens at a little above the platinum point. Using a single tube the value 1746° was obtained, with two tubes 1750°. Tests were also made in an iridium tube furnace, where there was no possibility of a reducing atmosphere. So good black-body conditions were obtained that the platinum was quite invisible. A piece heated to 1747° and removed was found not melted; one heated to 1759° and removed was found melted.

The use of the optical pyrometer depends upon the assumption that the object sighted upon emits black-body radiation. This is the case if the object is within a vessel at uniform temperature, and is viewed through a relatively small opening in the vessel. This can readily be accomplished in the apparatus used, but under such conditions it would be impossible to distinguish the sample, owing to the uniform brightness of the sample and its environs. In practice, the sample was placed slightly below the hottest part of the furnace, in such a position as to be barely distinguishable. This requires only a temperature difference of about 5°. When the temperature of a sample had almost reached the melting point, the temperature was raised more slowly and the sample was

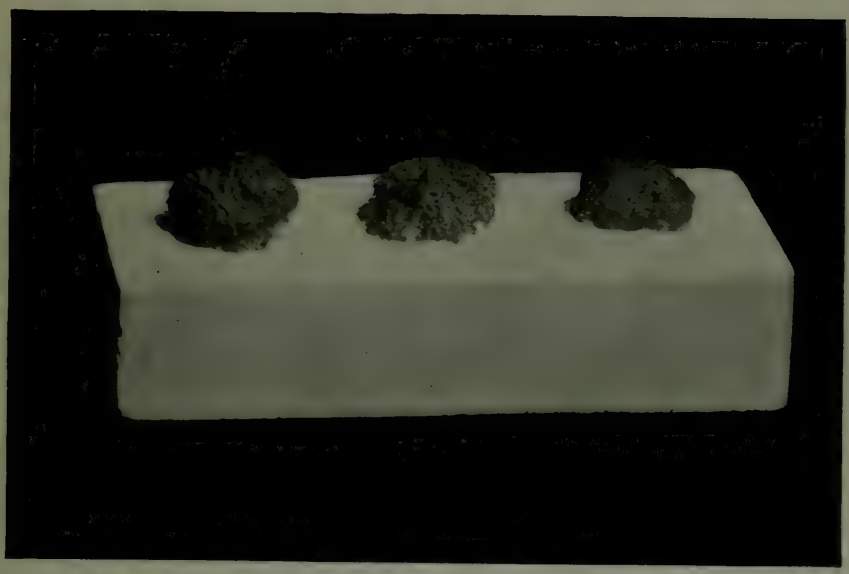
[7] Heinecke, Zs. angew. Ch., 21, p. 687; 1908.

observed continually. When it was seen to melt, a final temperature measurement was made and the heating current was immediately stopped, thus preventing the temperature from rising any higher. The observation was then verified by an examination of the sample after its removal from the furnace.

An idea of the degree of definiteness of the melting points may be obtained from Fig. 4 and Fig. 5, in which are shown samples which have been heated to successively higher temperatures. Fig. 4 may be taken to represent the usual degree of definiteness. The sample heated to 1680° C appears unaffected; that heated to 1695° shows very slight signs of fusion; that heated to 1705° is completely fused; 1705° was taken as the melting point. Fig. 5 shows perhaps the least definite melting point found. Complete fusion occurred at 1620°, but there was partial fusion at considerably lower temperatures; 1600° was taken as the melting point.

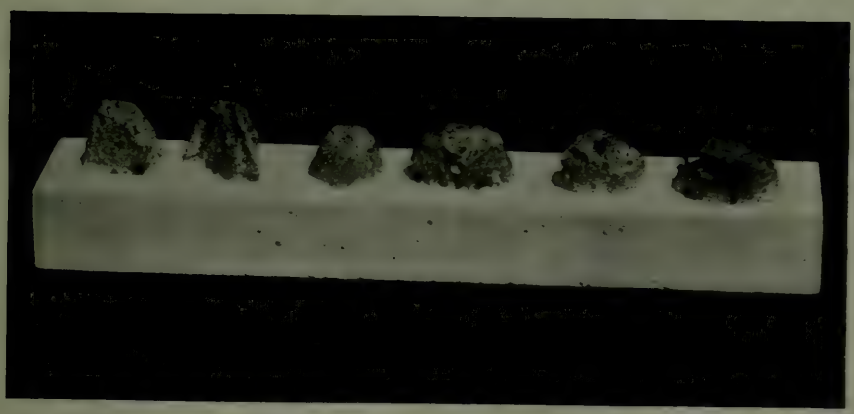
Near the melting point samples were heated at the rate of about 10° per minute. This rate of heating was quite slow enough, as a temperature measurement can be made in a few seconds, and a slower rate of heating near the melting point was found to give the same results. The entire time required for heating a sample from room temperature to its melting point was 30 to 40 minutes. Experiments were made to determine whether samples could undergo any change in melting point as the result of heating in the vacuum furnace. Samples of various kinds were heated in the furnace to about 1550° for about six hours, and their melting points were then determined. The results are given in Table I.

It appears from the table that Nos. 14 and 27, which are bricks of low melting point, melted at a somewhat higher temperature after long heating, while the other bricks were unaffected. The melting point of No. 27 is less definite than that of most bricks. This increase of melting point might be accounted for upon the assumption that the brick consisted of two materials existing in distinct particles, one sort having a lower melting point than the other, these two materials becoming run together after long heating near the melting point, producing a material of higher melting point than that of the more fusible of the original materials. The appearance of samples of No. 14 and No. 27 after heating for



1680° 1695° 1705°

Fig. 4



1570° 1580° 1590° 1600° 1610° 1620°

Fig. 5

TABLE I

Sample	Material	Determinations of melting point without previous heating	Determinations of melting point after six hours heating
		deg	deg
14	Fire clay	1635	1655
		1630	1655
27	do	1600	1635
		1610	1630
		1600	1635
		1585	1640
		1595	....
48	do	1710	1705
		1705	1695
		1705	....
		1700	....
		1705	....
20	Bauxite	1740	1740
		1745	1730
41	Silica	1705	1695
		1700	1700
		1695	....
		1695	....

a short time to near the melting point supports this explanation. Sample No. 27 is shown in Fig. 5. After the six hours heating they appeared more uniform. Long heating in a vacuum would tend to vaporize the more volatile constituents of the brick, and this might produce an appreciable increase of melting point.

The most common fire brick are those made of clay, of which the essential ingredient is kaolin, $Al_2O_3,2SiO_2,2H_2O$. Shepherd and Rankin[8] found that the only compound of alumina and silica that can exist in the neighborhood of the melting points is sillimanite, Al_2O_3,SiO_2. It follows that clay when near its melting point is no longer a single compound but a mixture of Al_2O_3,SiO_2 and SiO_2. Hence, the melting point of pure kaolin, like that of fire brick, can not be expected upon theoretical grounds to be perfectly definite, but fairly definite results are obtained when the

[8] Loc. cit.

visible flow is taken as the criterion of fusion, as in the case of fire brick. Two samples of white kaolin, one English, the other probably English also, both melted at 1740°. A sample of brownish white German kaolin melted at 1735°. Therefore, the highest melting point that can be attained in brick containing nothing more refractory than kaolin is 1740°. When an excess of alumina is present, as in bauxite brick, the melting point may be higher.

A few brands of silica brick were tested. Pure silica melts at about 1600°.[9] However, the fused silica possesses such extreme viscosity near the melting point that it does not flow or change shape distinctly until considerably higher temperatures are reached. I have obtained 1750° as the *apparent* melting point of pure silica, i. e., the temperature at which it flows distinctly. This temperature, however, is naturally a very indefinite one. The temperature at which silica bricks flow distinctly is more definite.

Bauxite brick are made from bauxite, $Al_2O(OH)_4$, containing usually considerable quantities of other material. Bauxite, of course, becomes converted to alumina, Al_2O_3, when heated. Pure alumina melts at about 2050°.[10] None of the bauxite bricks examined approached this melting point. A single sample of bauxite was tested and found to melt completely at 1820°, the centers of the nodules melting at 1790°. A sample of bauxite clay melted at 1795°.

One brand of magnesia brick was examined and found to melt at 2165°. The melting point of pure magnesia is more or less in doubt at present. It is to be expected that it would be higher than that of the impure magnesia brick. This brick contained a large quantity of iron and was of a dark brown color. When heated for a few minutes to near its melting point it became white. This occurred both in the electric vacuum furnace and in an oxy-hydrogen flame. It might result either from the vaporization of the iron, or from the formation of a colorless compound of iron and magnesia. An analysis of the specimens has shown that the heated samples contain much less iron.

[9] Day and Shepherd: J. Am. Chem. Soc., 28, p. 1089; 1906.

[10] A paper on the melting points of pure refractory oxides is in preparation.

One brand of brick made from chromite, FeO,Cr_2O_3, was examined. It was found to melt at 2050°. A sample of natural chromite from a different source melted at 2180°.

Silicon carbide, SiC, has been used as a refractory material. At very high temperatures it decomposes without melting. Tucker and Lampen[11] state that it decomposes at 2220°. Results in close agreement with this have been obtained by Gillett[12] and by Saunders.[13] This is undoubtedly correct for decomposition under ordinary conditions, but silicon carbide can be heated for a short time to much higher temperatures without complete decomposition. It was thought that by very rapid heating it might be possible to reach the melting point of the silicon carbide before decomposition was complete, although such a melting point would probably have only theoretical interest. With this object, a few grams of silicon carbide was placed in a graphite crucible, which was placed in a second larger graphite crucible to give more uniform temperature, and the whole was heated in an arc furnace at atmospheric pressure, the temperature being measured by sighting the optical pyrometer through a narrow graphite tube inserted in the top of the crucible. A temperature of 2700° or more was reached and was maintained for a few minutes. The silicon carbide was about half decomposed, leaving a residue of carbon, but showed no indication of fusion.

The results for fire brick will be found in Table II. Samples 1 to 26 are identical with the samples of the same numbers studied by Bleininger and Brown.[14] All the bricks tested were made in the United States. Each melting point given is the mean of at least two determinations. The mean of the melting points of the 41 samples of fire-clay bricks is 1649°.

The analyses of a large number of the fire-clay bricks studied are available,[15] but it does not seem possible to establish any very definite relation between composition and melting point. Since

[11] Tucker and Lampen: Jour. Am. Chem. Soc., 28, p. 853; 1906.
[12] Gillett: Jour. Phys. Chem., 15, p. 213; 1911.
[13] Paper presented before the American Electrochemical Society, May, 1912.
[14] Loc. cit.
[15] Bleininger and Brown, loc. cit.

TABLE II

Melting Point of Various Bricks

Sample	Melting point	Sample	Melting point
Fire-clay brick:	Deg	**Fire-clay brick—Continued,**	Deg
1	1630	34	1570
2	1635	35	1650
3	1605	36	1590
4	1605	37	1630
5	1705	38	1660
6	1705	47	1725
7	1700	48	1705
8	1700	49	1715
9	1675	[16] 53	1635
10	1710	[16] 54	1635
11	1660	[16] 55	1685
12	1555	[16] 56	1605
13	1635	**Bauxite brick:**	
14	1630	19	1760
15	1655	20	1740
17	1650	44	1720
21	1615	45	1785
22	1640	46	1720
23	1660	50	1665
24	1660	51	1565
25	1715	52	1590
26	1695	**Silica brick:**	
27	1600	39	1700
28	1695	40	1705
29	1595	41	1700
30	1560	**Chromite brick:**	
31	1600	42	2050
32	1650	**Magnesia brick:**	
33	1655	43	2165

[16] Samples 53, 54, 55, and 56 are of the same brands as 4, 9, 7, and 17, respectively, but from different lots.

the bricks contain about eight different constituents in quantities sufficient to affect the melting point, and since the melting point may also be affected by lack of homogeneity in the material, it is obvious that a prediction of the melting point upon the basis of a chemical analysis would be uncertain. If the melting points are compared with the results of tests under load conditions at 1300°[17], it is evident that there is little relation between the two.

[17] Bleininger and Brown, loc. cit.

SUMMARY

1. The melting points of 54 samples of fire brick, including fire-clay, bauxite, silica, magnesia, and chromite brick, have been determined in an electric vacuum furnace, the temperature being measured with an optical pyrometer (Table II).

2. The following melting points of materials important in the manufacture of fire brick were determined:

	Deg.		Deg.
Kaolin	1740	Bauxite	1820
Pure alumina	2050	Bauxite clay	1795
Pure silica	[18] 1750	Chromite	2180

3. An improved method of calibrating the Holborn-Kurlbaum optical pyrometer is described.

Mr. H. P. Greenwald and Mr. S. E. Moore have rendered efficient assistance in carrying out this work.

WASHINGTON, June 15, 1912.

[18] This is not the true melting point but represents approximately the temperature at which silica flows distinctly.

DEPARTMENT OF COMMERCE AND LABOR

TECHNOLOGIC PAPERS

OF THE

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S. W. STRATTON, DIRECTOR

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COMPARISON OF FIVE METHODS USED TO MEASURE HARDNESS

BY

RALPH P. DEVRIES, Assistant Physicist

Bureau of Standards

[JULY 22, 1912]

WASHINGTON

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3

TECHNOLOGIC PAPERS

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S. W. STRATTON, Director

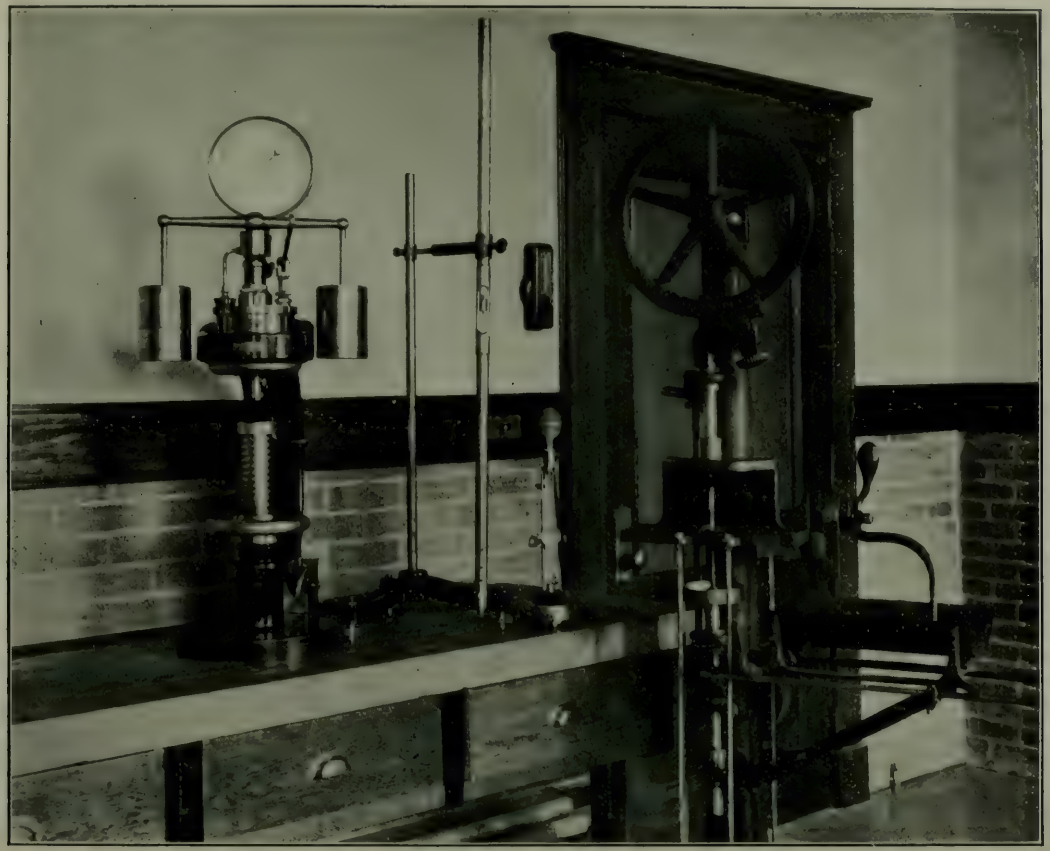
No. 2

COMPARISON OF FIVE METHODS USED IN MEASURING RAINFALL

BY

ROBERT E. HORTON
Assistant Professor of Physics, Union College

ISSUED
MAY 15, 1907



Brinell Ballantine Shore Keep

Fig. 1.—*Four hardness measuring instruments (the Brinell tester may be used with sphere or cone)*

COMPARISON OF FIVE METHODS USED TO MEASURE HARDNESS

By Ralph P. Devries

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1. INTRODUCTION

To the metal worker, and especially to the user of iron and steel, the hardness of metal, whether it is compression, abrasion, or cutting hardness, is one of its most important properties. The results of hardness measurement depend to some extent upon the kind of stress applied. Thus, by compression hardness we mean the resistance a substance offers to indentation by another body. Abrasion hardness is the resistance offered by a smooth surface to scratching. The resistance which a metal offers to drilling or working in any machine tool is designated as the cutting hardness. The methods of measuring hardness in use at the present time are the result of the growing need for information concerning this property. These methods do not conform to the more or less theoretical definitions which have been proposed at various times. They represent the ideas of men interested in finding a solution to the problem that should conform to the needs of the workshop and to the demands of actual practice.

After looking over the field it was decided to investigate only those methods which seem the most promising and which have

recently been developed. It is hoped that the study of hardness measurement may assist in developing a standard method of testing. The object of this investigation is to determine to what extent agreement exists between the results obtained by methods which are apparently in no way related to each other. In this preliminary work no attempt has been made to do more than to obtain comparative results for a series of metals which would be sufficient to show the performance of the individual instruments. Consequently no determinations have been made of the elastic constants or other properties of the metal, such as action under alternating stresses, impacts, cold bending, torsion, tension, or compression, although it is evident from the nature of the problem that these constants and properties are necessary for the interpretation of results.

As early as 1722 Reaumur originated a test for hardness which depends upon the principle that a harder metal scratches a softer one. Since that time various forms of sclerometers have been introduced, all of which depend upon this principle. To Brinell we owe the introduction of a method of hardness measurement which can be easily applied and the results of which can be expressed in definite physical units.

Brinell originated this method in 1900 while chief engineer and manager of the Fagersta Iron & Steel Works in Sweden. The method as he developed it is based upon determining the resistance offered to indentation by a hardened steel sphere when this sphere is placed on the material under investigation and subjected to a given pressure. He defined the hardness numeral as the ratio of the pressure on the sphere to the area of the spherical indentation produced.[1]

[1] H. Hertz first defined hardness as the mean pressure which exists at the center of the indentation when the material under test has just reached its elastic limit. This definition he applied only to bodies which have surfaces of such a form that a circular indentation results when they are pressed together. Hertz confined his hardness measurements to glass and similar brittle substances in which the attainment of the elastic limit is denoted by the appearance of a circular fissure around the contact area. Such a fissure does not necessarily denote that the material at the center of the indentation has passed its elastic limit. Hertz has shown that it is impossible to apply his definition to metals, because there are no means of telling when the elastic limit is reached at the center of the indentation. (For the mathematical development of the Hertz equations, see H. Hertz Gesammelte Werke, vol. 1, p. 155 ff., or Annalen der Physik; vol. 14, 1904, p. 153 ff. For discussion of the limitations of measuring hardness according to the Hertz definition, see vol. 51, Zs. des Ver. Deutscher Ingenieur Prüfverfahren für Geharteten Stahl unter Berücksichtigung der Kugelform Prüfungs ergebnisse Elastische und Bleibende Form anderungen. R. Stribech; vol. 52, Zs. des Ver. Deutsch. Ingenieur, Unter suchungen über Harte Prüfung und Harte. E. Meyer. C. Bach. Elasticitat und Festigkeit, verlag von Julius Springer.)

Since Brinell proposed this method it has been investigated by Le Chatelier,[2] Leon,[3] Malmstrom,[4] Meyers,[5] and others.

The cone test, which is a modification of the sphere test, was first proposed and investigated by Ludwik. The principle of the method is the same as that of the sphere except that a cone of 90 angular opening is substituted for the sphere.

For the measurement of the workability or cutting hardness of metals Bauer proposed a method which depends in principle on the depth of hole drilled in a given time by a drill running at a constand speed and under a constant pressure.

In 1906 Shore originated a hardness-measuring instrument, the action of which depends on the rebound of a hardened steel hammer when it is dropped upon the substance under investigation.

The Ballantine method depends upon the amount a leaden disk is indented when it transmits through an anvil the energy of a falling hammer to the metal to be tested.

2. THE BRINELL TEST

The Brinell test can be carried out in any machine capable of furnishing and measuring the pressures required to force the sphere into the metal. The apparatus used in this work was manufactured by Aktiebolaget Alpha, of Stockholm, Sweden, and is shown in Fig. 2. Accompanying this instrument is a special microscope which can be used for measuring the diameter of the indentation made by the sphere.

The method of carrying out the test as recommended by Brinell is to indent the metal by a sphere subjected to a pressure of 500 kilograms for the softer and 3000 kilograms for the harder metals. The diameter of indentation is then measured, and from it the depth of indentation is calculated from the formula

$$t = D/2 - \sqrt{D^2/4 - d^2/4}$$

where t is depth of indentation
D is the diameter of the sphere
d is the diameter of indentation.

---

[2] Revue de Métallurgie, 1906, No. 2.

[3] Die Brinellsche Härte probe und ihre praktische Verwendung. Proceedings International Association for Testing Materials, 1906.

[4] Stahl and Eisen, 1907, No. 50.

[5] Untersuchungen über Härte prüfung und Härte. Zeitschrift des Vereines Deutscher Ingenieure, 1907.

The measure of the hardness or hardness numeral was then calculated from the formula

$$\text{H. N.} = \frac{P}{\pi t D}$$

Where P is the entire pressure on the sphere and πtD is the area of the spherical indentation.

It has been shown by different investigators that the hardness numeral as thus obtained is dependent on the size of the sphere and the load applied in making the indentation. E. Meyer consequently advised that the mean pressure over the projection of the spherical concavity upon a plane perpendicular to the axis of pressure be taken as the hardness numeral. A. Martens[6] and E. Heyn have suggested as the hardness numeral that load which is required to produce an indentation of 0.05 mm in depth. They measured the depth of indentation directly at both high and low pressures and found that a linear relation existed between the two quantities only at very low pressures. Their work was carried out on special apparatus. The author found it advisable to use a different method to investigate the relation between depth of indentation and load at both high and low pressures throughout a range of 100–3000 kg.

DESCRIPTION OF METHOD

A micrometer microscope reading directly to 0.001 mm was mounted on a stand at a fixed distance from the apparatus. To obtain the depth of indentation the cross hairs were first set upon a fine line on the piston when the test piece had been brought into contact with the sphere. An initial reading was taken. The load was then applied and removed before the second or final reading was made. The difference between the initial and final reading is the depth of indentation of the sphere. The load was removed before taking the final reading so that the compression of the sphere and the different parts of the apparatus lying below the line marked on the piston should not be added to the difference already mentioned. The accompanying sketch, Fig. 2, of part of the apparatus and a typical curve for loading and unloading, Fig. 3, illustrate the method.

[6] Vorrichtung zur vereinfachten Prüfung der Kugel druckhärte und die damit erzielten Ergebnisse Zeitschrift des Vereines Deutscher Ingenieure, 1907.

Fig. 2 shows the piston on which the reference line is drawn. The test piece rests on the head, r, which is raised or lowered by the screw. When the test piece has been brought into contact with the sphere the desired pressure P is applied. The piston moves downward a distance equal to the depth of indentation, plus the amount of compression of the sphere and the piston. In Fig. 3 this distance is denoted by OR. When the pressure is released the piston does not return to its original position, but to a point indicated by S on the curve of unloading. The distance OS is then the depth of indentation. It is equal to OR, the entire travel of the piston minus SR the compression of the sphere and piston.

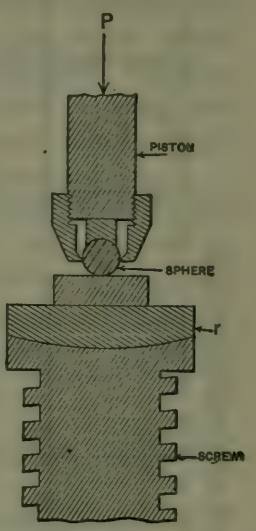

Fig. 2.—*Section of part of Brinell hardness tester*

It was found difficult to bring the test piece into contact with the sphere without indenting it and applying a small initial load. The method used in measuring the depth makes it necessary that the sphere shall begin to indent the metal as soon as the piston begins to travel downward. A small initial pressure was therefore applied before taking the initial reading of the microscope. When

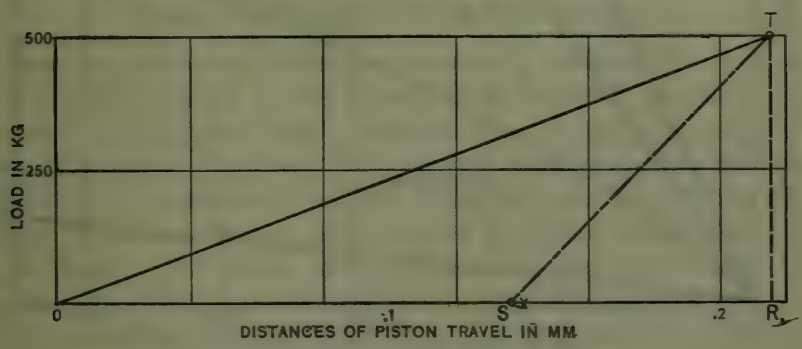

Fig. 3.—*Typical curve of loading and unloading*

the load was released, it was released not to zero, but to the initial load. By releasing the load to zero and bringing it back to the

initial load the measurement of the depth of indentation checked to 0.001 mm.

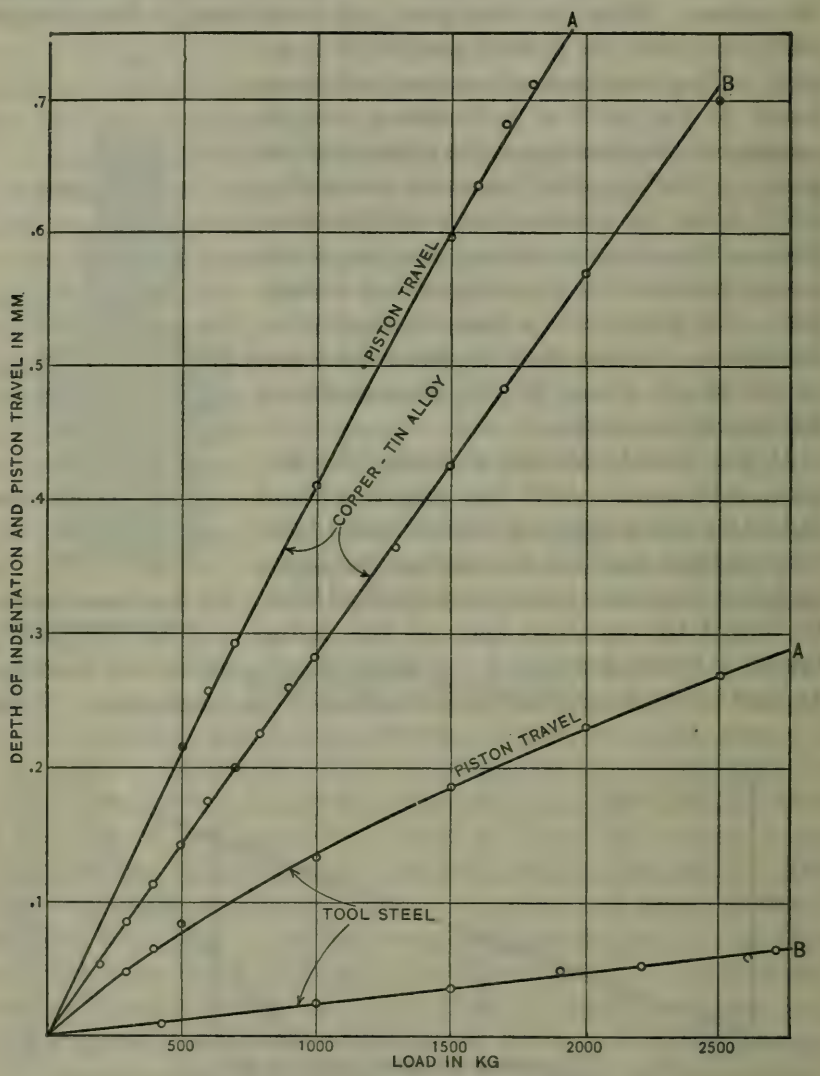

Fig. 4.—*Load-depth relation for two metals*

The total downward travel of the piston was measured for several metals. These results are shown in Fig. 4. The actual depth of indentation as measured is also plotted for easy comparison.

Curve A shows the total downward travel of the piston. Curve B is the actual depth of indentation. The difference between any ordinate of curve A and B represents the compression of the different parts of the apparatus lying below the reference line. Any measurement of the depth of indentation must totally exclude these elastic compressions. It seems probable that Martens and Heyn may have encountered difficulties in doing this, because they state that when their curves deviated from a straight line some of them curved upward and some downward.

The depths of indentation of ten different metals were measured at various loads. These metals ranged from very high carbon steels to metals as soft as copper and aluminum. They were subjected to no special heat treatment and very little was known of their composition. That any single measurement of depth did not give identical results on different parts of the same bar for the same pressures was rather to be expected.

The load was held constant during 15 to 30 seconds, respectively, for the harder and softer metals.

This time was found sufficient to establish equilibrium between pressure and resistance for all of the metals tested. In Fig. 5 the results obtained are plotted. These results show the existence of a linear relation between load and depth of indentation for all pressures from zero to three thousand kg.

ELASTIC DEFORMATION OF THE SPHERE

Since the hardness numeral as ordinarily calculated is a function of the diameter of the sphere, it is necessary to study the behavior of the sphere under compression. A specially prepared bar of Bessemer steel was used for this purpose. This bar was subjected to a temperature of 860° C. for one hour in an electrically heated furnace. It was then cooled to room temperature in eight hours. The depth and diameter of indentation made by loads ranging between 200 and 3000 kg were accurately measured.

It is sometimes difficult to measure the diameter of an indentation accurately, because the line of demarcation between indented and unindented metal is not always well defined. In the case of the softer metals it is far from being circular.

The special steel bar and most of the harder metals showed a well-defined bounding edge and the diameter of indentation was therefore easily measured. The measurements obtained on the steel bar are plotted in Fig. 6.

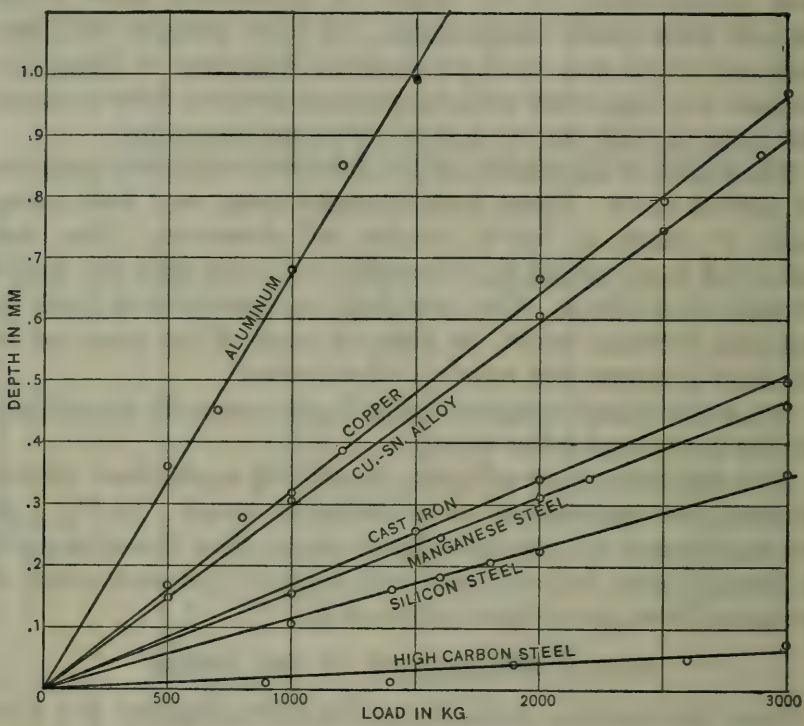

Fig. 5.—*Relation between load and depth of indentation in the Brinell hardness test*

If the steel sphere is not elastically deformed under pressure, then the value of the radius calculated from the geometrical relation

$$R=\frac{d^2}{8t}+\frac{t}{2}$$

should check in every case with the known value of the radius. But if the sphere is elastically deformed, values thus calculated will give approximately the radius of curvature of the indentation. The indentation is actually a segment of a spheroid, but for the small indentations no appreciable error is introduced in assuming

it to be spherical. The values of the radius of curvature as calculated from the values shown in Fig. 6 are placed in Table I. The elastic deformation of the sphere is seen to be appreciable for this steel. The radii of curvature obtained for different metals are also placed in Table I for easy comparison.

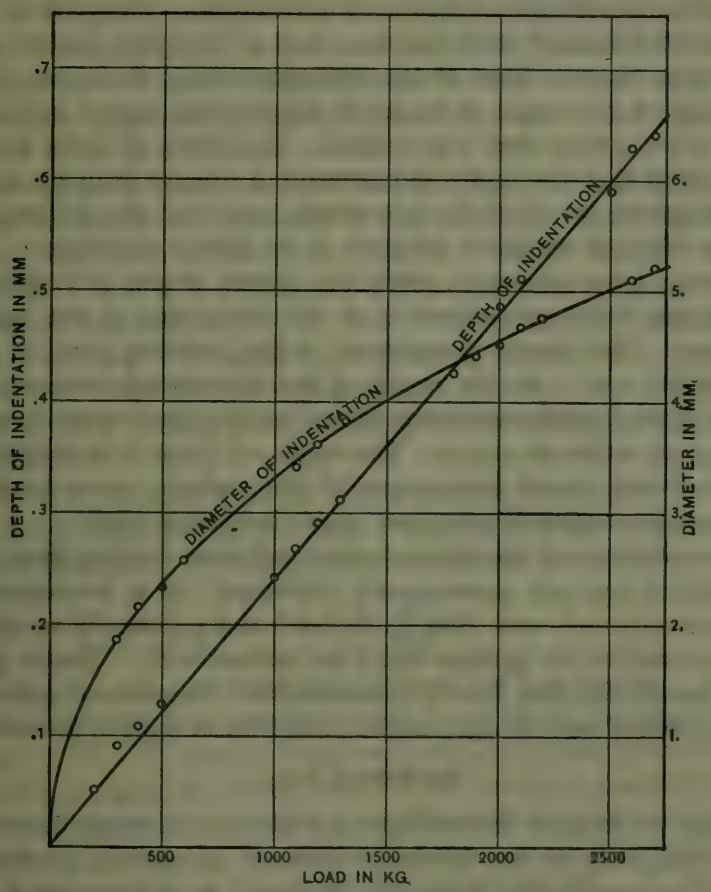

Fig. 6.—*Depth-dia. Load curves for Bessemer steel bar*

These particular metals were selected because they represent different indentation phenomena. The cast iron and bessemer steel, when subjected to pressure formed a ridge about the sphere by flowing up from beneath the sphere above the original surface of the metal. The manganese steel showed no ridge formation,

while the tobin bronze and copper vanadium alloy showed a negative ridge formation; that is, the metal near the circular edge was drawn in below the original surface.

For those metals which form a positive ridge the diameter of indentation measured is greater than the true value which corresponds to the measured depths of indentation. The radii of curvature of bessemer steel and cast iron is therefore greater than their true value. That of the manganese steel is correct, while the radii of curvature of the tobin bronze and copper vanadium alloy are less than their true values. The results of Table I, however, show that the radius of curvature is greater than the radius of the sphere for all of the five metals, and that the deformation of the sphere is relatively greatest at the lowest pressures.

At the lower pressures, when the sphere begins to indent the metal, the resistance offered is in the direct line of the applied pressure. The lateral component of the resisting force is then practically zero. As the depth of the indentation increases the effect of the lateral component of the resisting force tends to make the sphere retain its shape. The values of Table I show that the effect of the lateral component of the resisting force tends to decrease the radius of curvature under increasing loads.

Measurements of the sphere before and after loading show that the sphere was not permanently deformed. It is interesting in this connection to note that E. Meyer found practically no elastic deformation of the spheres which he worked with. This is probably due to the fact that he measured the diameter of sphere in the equatorial zone at right angles to the line of applied pressure.

The Relation $P = at$

When we consider that the sphere is always elastically deformed, the calculation of the hardness numeral as advised by Brinell retains no significance unless we replace D in the formula $P/\pi tD$ by the diameter of the sphere, of which the indentation forms a segment.

E. Meyer suggested that the mean pressure, Pm, equal to load divided by the area of projection of the spherical concavity be used as the hardness numeral.

But the relation between the load P and the diameter of indentation is not a simple one. $P = ad^n$ in which a the load required to produce an indentation of 1 mm in diameter, and n are constants that vary with every metal. Only when $n = 2$ does the hardness numeral become independent of the load. In none of the metals tested in this investigation was n exactly equal to 2. For purposes of comparison it will not do to arbitrarily take the hardness at 3000 kg, because E. Meyer has shown that for some metals the maximum hardness has already been attained at this load. For others it has not yet been reached.

The linear relation between load and depth of indentation suggests at once as the measure of hardness, that load which is required to produce an indentation of 1 mm in depth. In the formula $P = at$, a is a constant. It is the load required to produce an indentation of 0.1 mm in depth if t be expressed in tenths of mm. To use 0.1 mm would be preferable to one millimeter, for most of the indentations are less than one millimeter in depth. The values of a for the different metals are placed in Table V.

In order to have a more definite basis for comparison with the cone test the hardness numeral is also calculated on the basis of entire pressure P divided by area of spherical concavity.

$$\text{Expressed in symbols, H. N.} = \frac{P}{2\pi t R'} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where R' is the radius of curvature of the indentation. For the softer metals the hardness numeral is calculated for 500-kg pressure. This was done in order to avoid inaccurate measurements of the diameter of indentation. The hardness numeral of the harder metals was calculated for the load 3000 kg, because the depths of indentation are so small that an appreciable error would be introduced by a small error in measurement. If the value $P = at$ is substituted in equation 1 it becomes $\text{H. N.} = C/R' \ldots . (2)$

$$\text{where } C = a/2\pi$$

The product of H. N. and radius of curvature is a constant for all loads up to 3000 kg. Since the radius of curvature decreases with increasing loads the hardness numeral must increase. The values

placed in Table II show the variations of the hardness numeral for the different loads. The deformation of the sphere has therefore a very important bearing on the results of sphere hardness tests.

If the value of R′ is substituted in equation 1 it becomes H. N. = $P/\pi\left(\frac{d^2}{4}+t^2\right)$ ..... (3)

The hardness numeral suggested by E. Meyer is

$$\text{H. N.} = \frac{P}{\frac{\pi d^2}{4}} \quad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

It can be seen by comparing equations 3 and 4, that they will give practically the same results for low loads, but at the higher loads equation 4 will give hardness results that are much higher than those obtained by equation 3. The variation of the hardness numeral with the load is greater when it is calculated upon the projected area of the indentation than when calculated on the actual area of the indentation. Since equation 2 shows that the product of hardness numeral and radius of curvature is constant for a sphere 1 cm in diameter some measurements were made with a sphere 1.2 cm in diameter. The relation obtained between load and depth of indentation for several metals is plotted in Fig. 7. The hardness numerals $\frac{P}{2\pi tR'}$ are also placed in Table II. These values show a good agreement. It is not improbable that the hardness numeral is independent within certain limits of the size and hardness of the sphere.

THE CONE TEST

The sphere and cone test are both modified forms of a compression pressure test and can be carried out in the same apparatus. Ludwik[7] seems to have been the first to propose and use this test for hardness. He measured the depth of indentation by means of a device, the action of which depends upon the downward motion of the piston. The area of the conical indentation was calculated from the values of the depth of indentation. The hardness numeral was then computed by dividing the pressure by the area of the indentation.

[7] Die Kegelprobe: Ein neues Verfahren zur Härte bestimmungroon Materialen Verlag von Julius Springer.

Much has been claimed for the cone form of hardness test in preference to the sphere, the principal claim being that the circular cone makes indentations which are geometrically similar for differ-

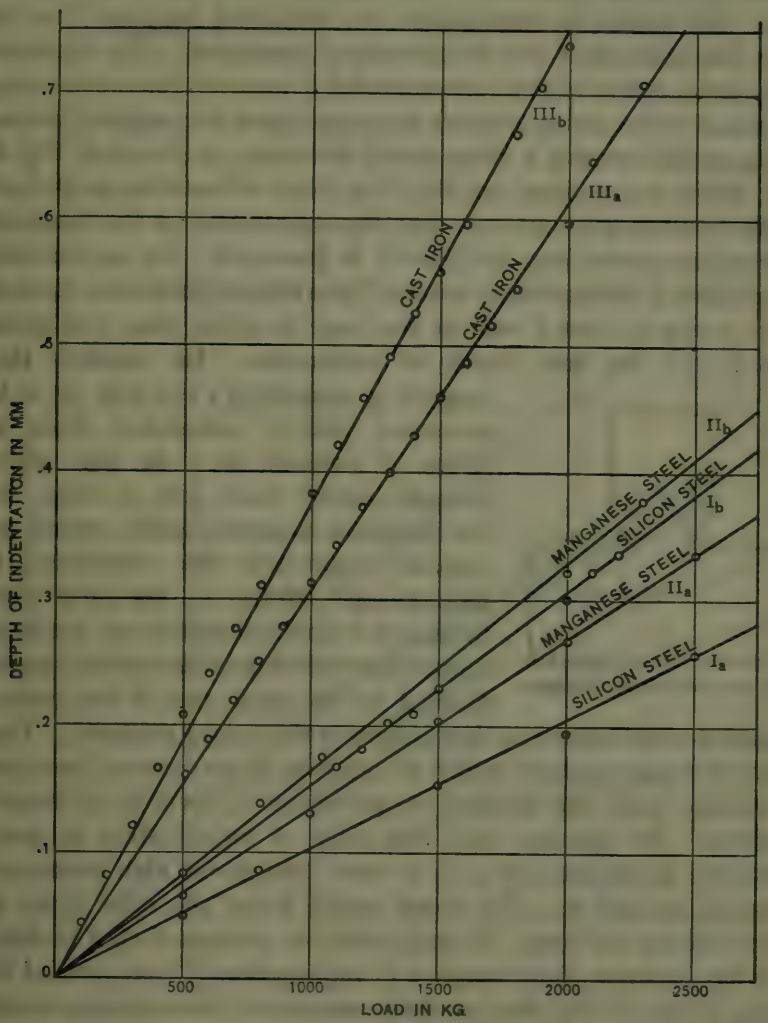

Fig. 7.—*Load-depth relation for spheres of different diameters*

ent pressures. Since the variation in the hardness numeral for different loads in the sphere test is due to the fact that the indentations are not geometrically similar, it was decided to carry out tests with cones of 60° and 90° angular opening.

All of the metals previously tested by the Brinell method were tested with cones of 60° and 90° angular opening. The depths of indentation were measured in the manner described in the sphere test. The depth of indentation was measured because it is the only dimension that can be accurately measured. The diameter of the indentation might be measured if it were not for the fact that the metal when under pressure flows up above the original surface of the metal forming a ridge about the cone, as shown in Fig. 8.

E. Meyer has pointed out that this ridge of metal supports part of the applied pressure and that the calculation of the hardness numeral as carried out by Ludwik is incorrect. He says in substance that if the hardness numeral is calculated from the formula H. N. $= .225\ P/t$ that it will be too large in value, since t as measured is not the true depth of indentation. He suggests that instead of measuring t (see Fig. 9), d be measured and t' calculated from it. Using t' instead of t in the above formula would then give a value for the hardness numeral which would accurately represent the resistance to indentation. Meyer in his own work measured d and calculated the hardness numeral on the basis of the entire pressure divided by the projection of the conical indentation on a plane at right angles to the axis of pressure. That either of these methods which he advised as corrections have any advantage over the method proposed by Ludwik is extremely doubtful. He assumes that the ridge of metal offers as much resistance to indentation as if it were solid metal with unstressed metal all around it. The metal which forms the ridge flows up from beneath the cone. It may safely be presumed that in doing so it has lessened the resistance to indentation of that part of the metal, so that if this effect could be measured the correction would probably have to be applied, but with the opposite sign. Moreover the amount of ridge formation for a given pressure depends upon the metal itself. It is attendant upon the test performed as much as the decrease of cross section of a tensile specimen for a given stress is dependent on the nature of the metal.

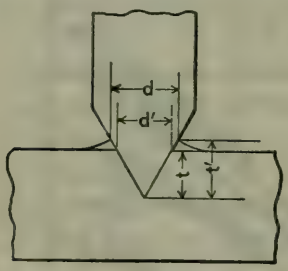

Fig. 8.—*Cone ridge formation*

In Fig. 9 the depths of indentations for various loads are plotted for several metals. If the relation between load and depth of indentation is a parabola, as would seem, then $P = at^n$, which may

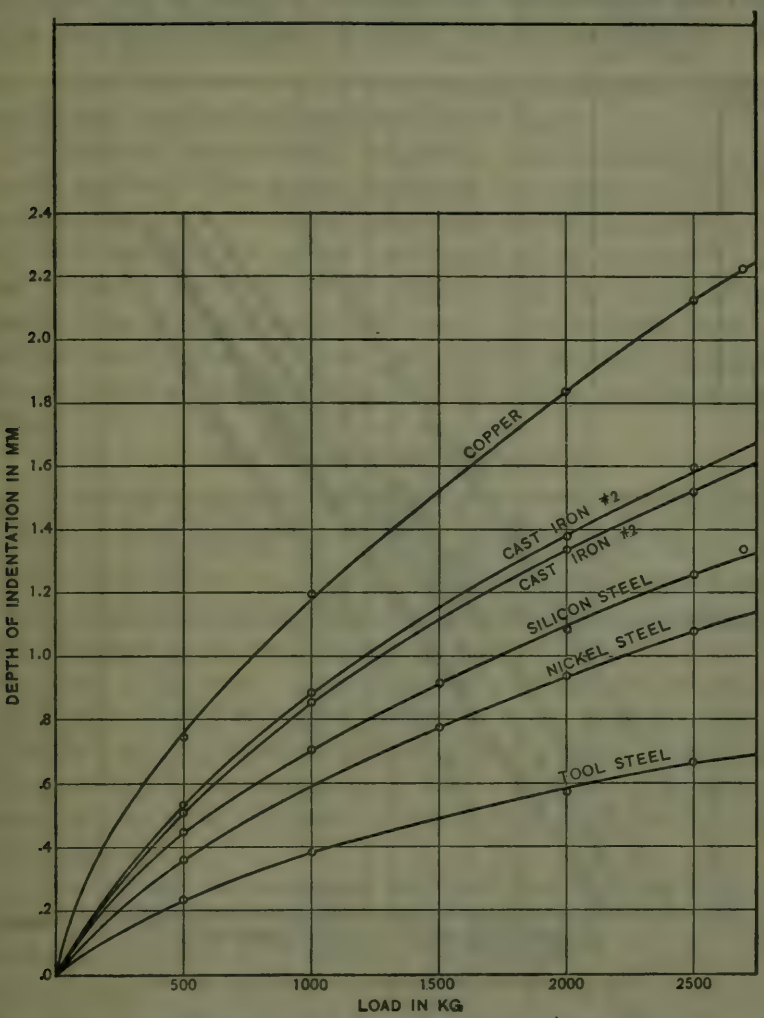

Fig. 9.—*Relation between load and depth of indentation in the cone test*

be expressed as $\log P = \log a + n \log t$. In Fig. 10, the relation of $\log P$ to $\log d$ is plotted for the metals of Fig. 9. Since the relation is a linear one the relation between load and depth of indenta-

tion is expressed by $P = at^n$. The value of n and a can be determined directly from the curves of Fig. 10. Some of the results which Ludwik gives in his paper are tabulated in Table III. The same table also contains the results as obtained in this investigation. The difference in the hardness numeral is easily seen to be

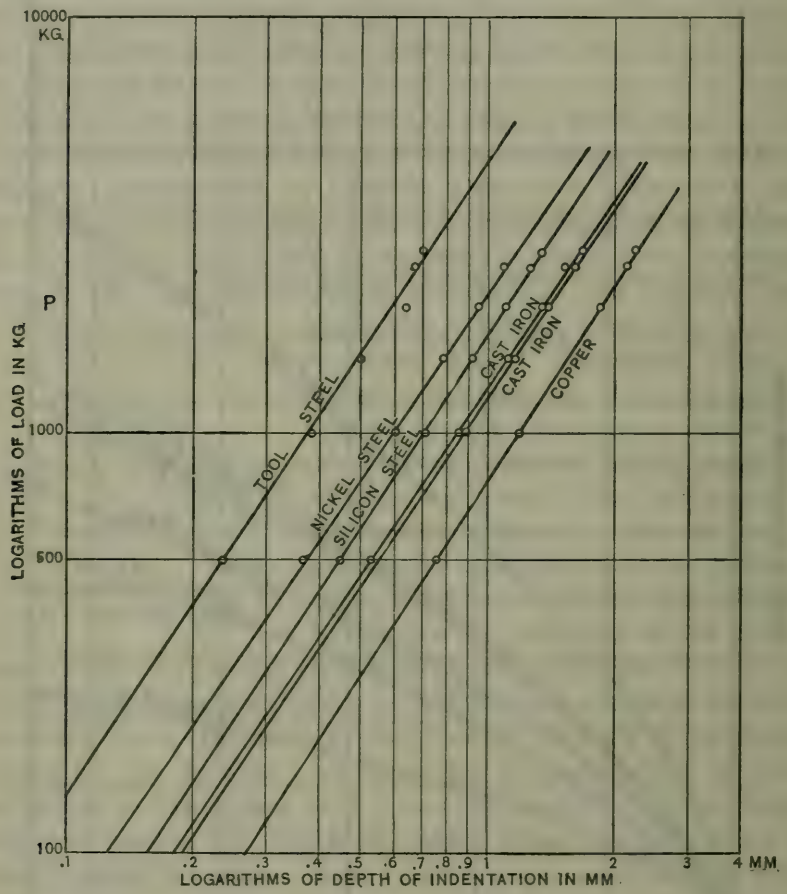

Fig. 10.—*Curves Log P=log a+n log t for the cone test*

due to the difference in the depths of indentation obtained. If these values of Ludwik's for the hardness numeral were correct, it would not be necessary to assume any particular load at which to calculate the hardness numeral. But the facts are that the hardness numeral decreases rapidly with increasing load. Lud-

wik seems to have been aware of the errors which exist in his measurements, for in a footnote he remarks that by making more careful measurements of the depths of indentation, the hardness numeral would decrease with increasing loads. He also states that the hardness numeral would have to be calculated at the higher loads; that is, at those loads where the depth of indentation changes only slightly with increase of load.

The hardness numeral has, therefore, been calculated for the load of 3000 kg. The results obtained are entered in Table V. For two grades of steel it was impossible to obtain results for the cone test, because the cones were appreciably blunted by the steel. Even in the case of the softer metals the cones become blunted after a limited number of tests. This limitation and the fact that the hardness numeral varies with the load shows that the cone test is more limited than the sphere in its practical applications.

3. THE SHORE SCLEROSCOPE

A cut of the scleroscope is shown in Fig. 1. The instrument briefly described consists of a pointed hammer which falls from a definite height through a guiding glass tube upon the metal to be tested. The height to which the hammer rebounds is the measure of the hardness and is read directly from a scale placed back of the glass tube. This scale is approximately 10 inches in height and is arbitrarily divided into 140 equal parts. The hardness numeral is therefore not expressed in definite physical units. This is not a disadvantage if the scleroscope is simply accepted as a hardness measuring device, but it leaves much to be desired for investigational purposes.

In this method of measuring hardness the hammer makes a permanent indentation in the metal under test. An attempt was made, therefore, to determine the hardness as the resistance to indentation. In order to do this, it is necessary to measure either the diameter or the depth of indentation. Both of these quantities are extremely small and the latter is inaccessible to all length measuring devices. Some measurements of the diameter of indentation were made, but in general this is impracticable, because the bounding edge of the indentation is not circular. In

the measurements referred to the greatest diameter of indentation amounted to only 0.005 mm.

It would be entirely practicable to determine the hardness numeral in the manner outlined if the hammer was enlarged and the height of fall increased so that the diameter of indentation could be measured accurately.

In working with the scleroscope it was found that the hammer must be calibrated after a certain number of tests. For this purpose a piece of steel hardened to 100 scleroscope measurement must be used. The rebound for any given steel can not be corrected by proportionate decrease or increase if the hammer gives a rebound either less or greater than 100 on the hardened steel. This shows that a slight change in the form of the hammer assigns the metal tested to a different position in the hardness scale. Although many things are stated by the inventor concerning the theory of the instrument, which can not be accepted without experimental confirmation, they will be discussed later in the paper which deals with the relations of the physical properties of metals to hardness. The hardness numerals of all the metals tested are entered in Table V.

4. THE BAUER DRILL TEST

The Bauer drill test differs essentially from the other hardness tests. It indicates the cutting hardness and has for its object the determination of the workability of metals. The ease or difficulty with which a metal is worked in any machine tool is known to depend upon the toughness and the abrasive qualities as well as the hardness. The drill test can not, therefore, be considered as being merely a test of hardness.

Since the drill test depends upon other qualities than hardness, it is evident that the results obtained should furnish instructive comparisons.

The machine which was used in this work is manufactured by William Keep and was designed for testing the hardness of cast iron. A cut of the machine is shown in Fig. 1.

The machine has for its essential parts (a) a fluted drill driven at constant speed; (b) a table upon which the metal to be tested is placed and from which weights may be suspended for securing

desired pressures; and (c) an autographic attachment which traces a curve whose ordinates are some constant multiple of the depth of hole drilled and whose abscissas represent some constant multiple of the number of revolutions required to drill a given depth. The drill was sharpened on a special grinder in such a manner that the rake and clearance was the same for every test.

The metal to be tested is securely clamped or otherwise held on the table. The weights needed to give the desired pressure are hung on the supports attached to the table. The point of the drill is allowed to drill into the metal before the diagram tracing attachment is thrown into gear. If the drill dulls it becomes apparent at once from the change of slope of curve. The drill must then be taken out and sharpened.

Of all the metals tested by the other methods only a few could be tested by the Bauer method. Some difficulty was encountered even in testing these. This was chiefly due to the fact that they had to be drilled at the same pressures in order to have a basis of comparison. It is a matter of common experience that the pressure applied to the drill and the speed at which it runs must be suited to the metal. Since the method depends upon the rate at which the metal is drilled for the measure of the hardness of workability, it is obvious that the results obtained for different metals are comparable only within very narrow limits.

The line traced by the autographic apparatus shows a linear relation between multiples of the depth of hole drilled and the revolutions required to drill it. The tangent which this line makes with the Y axis is taken as the hardness numeral. For metal as hard as the steel drill the line traced is the X axis. The hardness numeral of such metal is therefore infinity. The results obtained are placed in Table V. Each result is the mean of three separate determinations.

5. THE BALLANTINE HARDNESS TEST

The Ballantine instrument is shown in Fig. 1. Fig. 11 is a sketch of the essential parts of the instrument. The hammer H is fitted with a hardened cylindrical piece of steel E. The two springs S and S' are attached to the hammer and hold a leaden cylindrical disk of 0.6 cm. in depth and 1 cm. in diameter in the position

shown. The hammer is held in the upper part of the tube *T* by a trigger not shown in the figure. The anvil *A* in the lower part of the tube is free to move vertically.

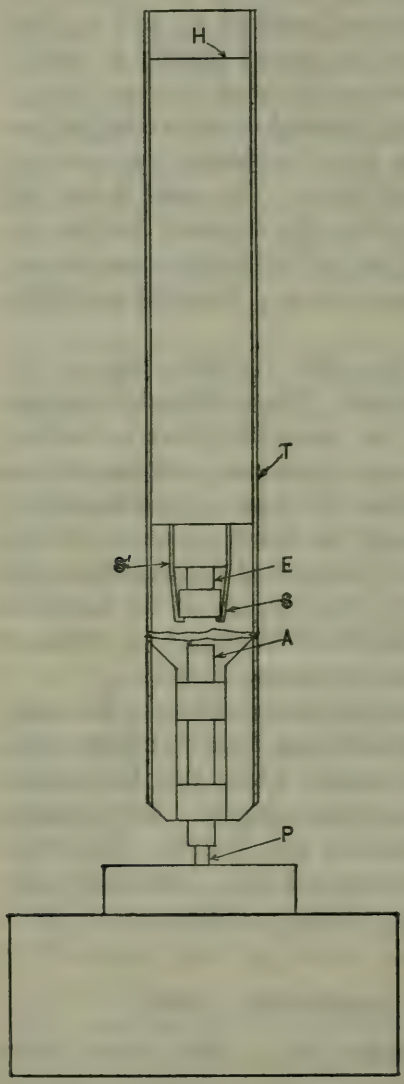

Fig. 11.—*Ballantine hardness tester*

The upper part of the anvil is a duplicate of the lower part of the hammer. The anvil terminates in a point *P*, which rests upon the metal to be tested.

The instrument is supposed to operate and give results as follows: When the hammer is released it falls on the anvil, and the force of the blow drives the point *P* into the test piece. The lead disk is then indented a certain amount, depending on the hardness of the metal. If the metal is hard, the disk will be indented more than if the metal is soft. The reciprocal of the depth of indentation of the lead disk is the hardness numeral.

Tests were made on 10 different metals, but the indentations of the lead disk were practically the same for the hardest and softest metals.

The instrument as it comes from the manufacturers has an anvil point which is a circular cylinder slightly upset at the end. Thinking to increase the sensitiveness of the apparatus, anvil points were provided which were circular cones of 120°, 90°, and 60° angular opening, respectively. The results of three copper-tin alloys obtained with these different points are given in Table IV. A

comparison of these results shows that the modified cone points did not serve the expected purpose.

The next modification introduced was to reduce the area of the lower end of the hammer and the upper end (F) of the anvil, the area being reduced in approximately the ratio 2:3. That neither of these modifications served the intended purpose is shown by the results placed in Table V.

For all of the metals tested the depth of indentation of the metal (not the disk) was very small, amounting in the case of the softest metal to about 0.3 mm. The energy of fall of the hammer is therefore practically a constant. This energy is spent in indenting the test piece, the leaden disk, and in heat. If a hard metal is tested, the indentation of the metal is small, but the work done may be no less than that required to produce a larger indentation in a softer metal. The experimental results seem to show that there remains only a constant fraction of the energy to do the work required to indent the leaden disk. This fraction of the total energy available can be a varying quantity for the different metals only when the total energy of the falling hammer is itself a variable quantity for every metal. This would be the case only for widely varying depths of indentations of the metal.

6. DISCUSSION OF RESULTS

The hardness numerals for all of the metals tested by the five different methods are entered in Table V. To enable the reader to see at a glance how these methods compare, the results obtained by the scleroscope, the sphere, and the cone method are represented graphically in Fig. 12. To obtain convenient numbers for graphical representation the hardness numeral of the scleroscope is multiplied by 100, that of the sphere $\left(\frac{P}{2\pi t R'}\right)$ and of the cone are multiplied by 10. The sphere numeral $\left(\frac{P}{t}\right)$ is unchanged.

If the five methods measured the same quantity, the series of ordinates of the points of hardness by one method would be proportionate to the series by any of the other methods. In these curves it is interesting to notice that the widest divergence between the Brinell and the Shore method occurs for those metals

which contain elements whose presence is generally supposed to contribute toughness rather than hardness to a metal. Consider, for instance, the copper-tin alloys numbered 1, 2, 3, and 4. Number 1 is an alloy of 90 per cent copper and 10 per cent tin. By the scleroscope it shows a hardness greater than that of tool

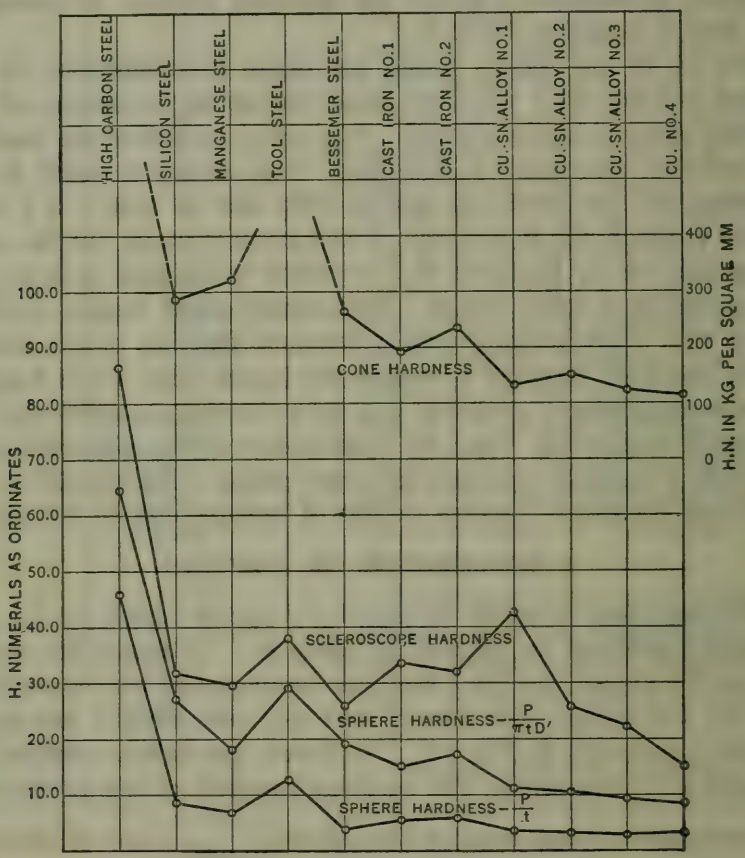

Fig. 12.—*Comparison of hardness numerals of different methods*

steel. By the Brinell test it shows a hardness not much greater than that of ordinary copper commercially pure. Number 2, an alloy of copper 8 per cent and 15 per cent tin, is harder than Bessemer steel or cast iron by the scleroscope. By the Brinell test it is only slightly softer than copper-tin alloy No. 1. By both the

scleroscope and the Brinell method the hardness for the copper-tin alloy series is in the same direction. Alloy No. 1 is the hardest, with numbers 2, 3, and 4 following in order. Compare this with the Bauer drill test hardness numerals and we see that the order is reversed. Alloy No. 1 drills the easiest, with Nos. 2, 3, and 4 following in the order named.

The cone and sphere tests give results that are quite concordant throughout. For these two tests a strict comparison can be made, for the results are expressed in the same units.

7. SUMMARY

The various methods for measuring sphere hardness are compared.

A method is given for measuring the depth of indentation which shows the existence of a linear relation between load and depth.

This method makes a rational sphere-hardness scale possible by the determination of one constant.

The effect of elastic sphere deformation on the hardness numeral is determined.

Cone-hardness numerals are determined by depth measurements. The results show that the law of similarity is not fulfilled in the cone test.

The cone test is also shown to be more limited in its practical applications.

The scleroscope hardness results are not in good agreement with the Brinell tests for the harder metals, and the lack of agreement is more noticeable for the alloys of the softer metals.

The Keep drill tests show that cutting hardness depends on a different property of a metal than resistance to indentation.

TABLE I

Radius of Curvature of Indentation for Different Metals

Load, in kg	Values of R', in cm for—				
	Bessemer steel	Cast iron	Tobin bronze	Copper vanadium alloy	Manganese steel
500	5.71	6.71	6.31	6.72	7.64
1000	5.79	6.46	5.83	6.46	6.98
1500	5.73	6.26	5.43	6.26	6.59
2000	5.59	6.16	5.13	6.16	6.24
2500	5.56	6.05	5.05	6.05	5.70
3000	5.57	5.91	5.06	5.91	5.43

TABLE II

Values of Hardness Numerals Obtained with Spheres of Different Diameters

Load, in kg	Hardness numeral							
	Copper for—		Manganese steel for—		Silicon steel for—		Cast iron for—	
	1.2-cm sphere	1-cm sphere	1.2-cm sphere	1-cm sphere	1.2-cm sphere	1-cm sphere	1.2-cm sphere	1-cm sphere
1000	86.5	83.4	179	177.5	215	214	136	137
2000	.....	.....	183	181.5	222	219	138	139
3000	.....	.....	187	185.6	225	225	140	144

TABLE III

Comparison of Results for the Cone Hardness Test

Load, in kg	Ludwik's data for copper: "t" in mm	H. N.	Author's results: "t" in mm	H. N.	Ludwik's data for "t" in mm	H. N.	Author's results: "t" in mm	H. N.
500	1.23	74.4	0.759	195	0.93	130	0.549	374
1000	1.74	74.3	1.201	154.9	1.32	129	.864	304
1500								
2000	2.46	74.3	1.844	132.0	1.85	132	1.343	256
2500	.....	.....	2.139	122.8	2.27	132	1.523	242
3000	3.00	75.0	2.435	114.0	2.27	131	1.683	239

TABLE IV

Depth of Indentation for Different Cone-Pointed Anvils in the Ballantine Test

Metal	Depth of identation in lead disks for circular cone anvils of—		
	120°	90°	60°
Cu.-sn-alloy 1	3.26	3.14	2.99
Cu.-sn-alloy 2	3.20	3.35	3.04
Cu. 4	3.18	3.17	2.95

TABLE V

Hardness Numerals of Different Metals by Five Methods of Test

Metal	Shore scleroscope	Hardness numeral				Bauer drill test	Ballantine test
		Brinell		Cone test			
		$\frac{P}{2\pi t R^1}$	$\frac{P}{t}$	90° cone	60° cone		
Carbon steel	86.1	641	4550	.....	.....	.....	3.2
Silicon steel	33.6	261	865	331	130	.....	3.0
Manganese steel	29.5	179	641	368	124	.....	3.3
Cast iron No. 1	33.3	149	536	191	68	.....	3.2
Cast iron No. 2	32.9	172	590	231	70	2.29	3.3
Bessemer steel	26.6	188	428	260	76	.....	3.3
Tool steel	37.8	289	1230	.....	.....	.....	3.3
Cu.-sn. alloy 1	42.4	110	460	130	50	.73	3.1
Cu.-sn. alloy 2	25.5	105	323	149	54	1.04	3.2
Cu.-sn. alloy 3	22.1	94	289	122	48	1.24	3.4
Copper 4	15	89	235	114	38	1.88	3.2

WASHINGTON, July 22, 1912.

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